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CORPS OF ENGINEERS

MISSISSIPPI RIVER COMMISSION

MODEL STUDY FOR THE IMPROVEMENT OF THE GALOP RAPIDS REACH OF ST. LAWRENCE RIVER

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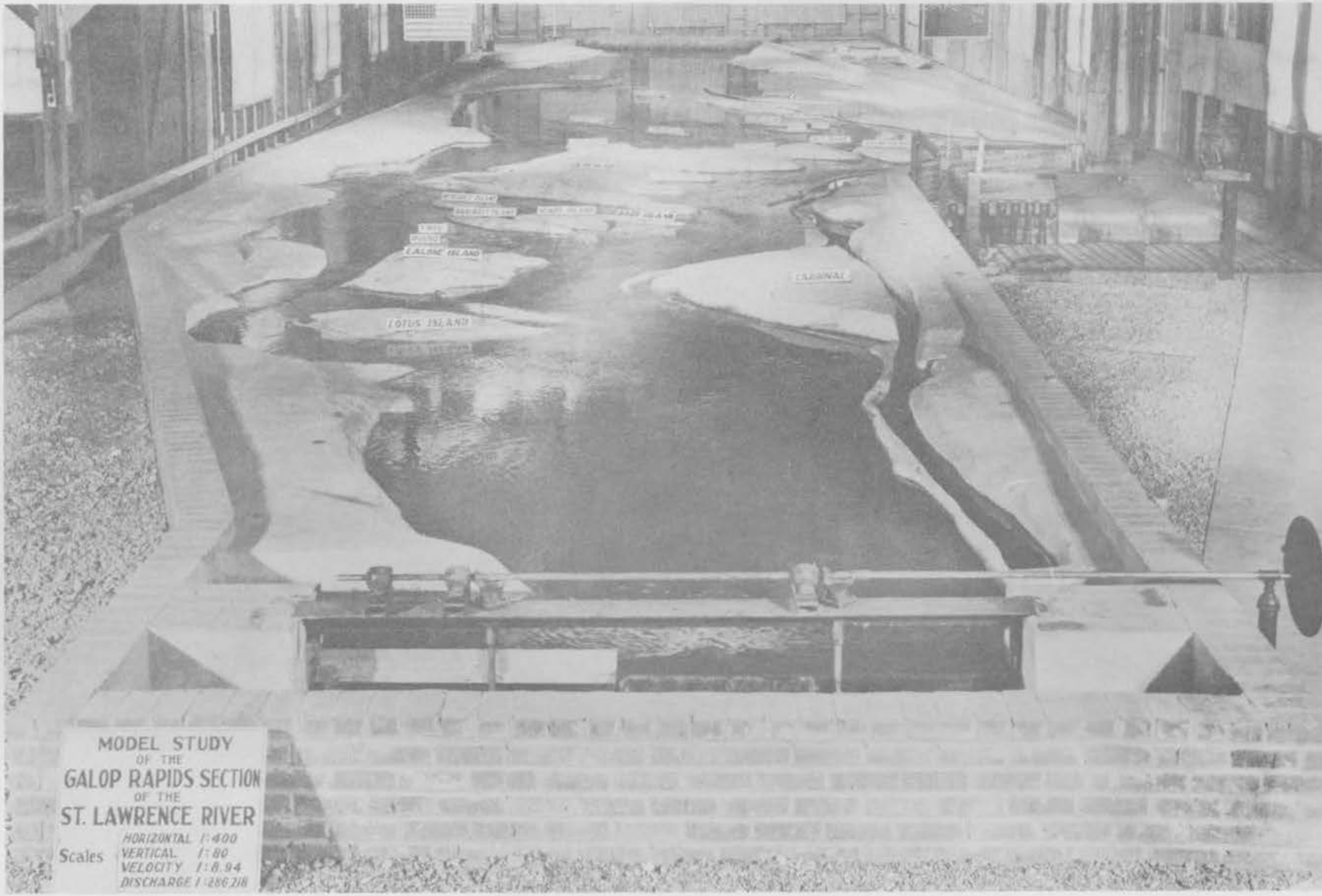
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MODEL STUDY FOR THE IMPROVEMENT OF THE GALOP RAPIDS REACH OF THE ST. LAWRENCE RIVER

SYNOPSIS

The model study of the Galop Rapids Section of the St. Lawrence River was conducted at the Waterways Experiment Station for the New York District, CE, during the period January 1943 to October 1945. The general purpose of the model study was to determine the relative merits of two plans proposed for improving the rapids for navigation and power development.

The plan for improving the Galop Rapids Reach adopted by the St. Lawrence River District, CE, in a review of the project during 1941-42 was called the "Recommended" Plan and is a modification of the 238-242 Single-Stage Plan designed by the Canadian Department of Transport. The principal features of the plan are a sinuous navigation channel through the American Galop Rapids and a hydraulic cut through Galop Island. Model tests of the "Recommended" Plan indicated that the plan as designed would not meet the prescribed velocity criteria. Based on changes indicated by the results of the model tests and in the light of additional information regarding the location of ledge rock, the "Revised Recommended" Plan was designed in the Office, Chief of Engineers, and tested in the model. This plan also failed to meet the velocity criteria; however, a

series of steps embodying various progressive modifications of the plan were tested until a modification of this design was obtained which produced satisfactory velocities.

In keeping with the general trend in the design of improvements for the Great Lakes by providing wider and straighter channels for the larger and faster ships now in use, the "Alternate" Plan was designed by the St. Lawrence River District, CE. This plan provided a practically straight waterway 1600 ft wide through the Drummond Island Channel and Galop Island to deep water below Lotus Island. Along the sides of the channel dikes were provided to prevent cross currents and to reduce velocities, the Lalone and Lotus Island south channel was enlarged and Spencer Island Pier was removed. Model tests of the "Alternate" Plan, as originally designed, revealed that the plan would not satisfy the prescribed velocity criteria for navigational purposes. Further testing in the model indicated that many of the training dikes produced unfavorable results; it was found that only those dikes along the south edge of the navigation channel between Butternut Island and Lotus Island produced beneficial results. From this series of tests the "Improved Alternate" Plan was developed. Test results of this plan showed velocities in the navigation channel considerably lower than the design criteria, indicating that the plan was over designed and considerable economies could be obtained by reducing the widths of the cuts. Accordingly, the model studies were extended to include various plans incorporating reduced channel widths. From this series of tests the "Final Alternate" Plan was developed which met the velocity criteria and was much cheaper to construct than the original "Alternate" Plan.

Cost studies made concurrently with the model tests indicated that the modifications required of the "Recommended" Plan to make it conform to the design criteria did not affect the cost greatly. However, modifications of the "Alternate" Plan for the same purpose reduced the cost approximately $20,000,000 with the result that the cost of the "Final Alternate" Plan would be about the same as that of the "Revised Recommended" Plan.

PART I: AUTHORIZATION

1. The model study of the Galop Rapids Section was authorized by the Chief of Engineers on 23 January 1943. The study covered channel work in the vicinity of Galop Island (mile 67 to 74) and included all items listed under Feature No. 1 of the St. Lawrence River Project, Final Report, 1942, prepared by the Corps of Engineers, U. S. Army, U. S. Engineer Office, Massena, N. Y. The design and construction of the model were undertaken immediately, and the first operation of the model was begun in May 1943. The testing program was completed in October 1945. Interim reports containing data covering the Verification, Base Tests, Recommended Plan, and Alternate Plan were prepared and submitted during the course of the investigation. This present report supersedes all previously submitted reports on the model study.

PART II: THE PROTOTYPE

The St. Lawrence River

2. The St. Lawrence River has its source in the Great Lakes and forms with them a waterway extending from the interior of the North American Continent to the Atlantic Ocean. A map of this area is shown on plate 1. The river between Lake Ontario and the city of Quebec is 342 miles long. The upper 113 miles, between Lake Ontario and St. Regis, constitute the boundary between the United States and Canada; downstream from St. Regis, the river is entirely within Canadian territory. Between Chimney Point and Montreal, a distance of 114 miles, the river is generally constricted and steep. Forty-six miles of this steep portion are in the International Section and 68 miles in the all-Canadian Section.

3. The river above Montreal may be divided into five more-or-less distinct sections: (a) the generally deep lake-like Thousand Islands Section extending 67 miles from Lake Ontario to the first swift water near Chimney Point; (b) the International Rapids Section embracing the 46 miles of rapids and swift water between Chimney Point and Lake St. Francis; (c) the Lake St. Francis Section extending 27 miles through that lake to the end of deep water at its foot; (d) the Soulange Section embracing the 18 miles of rapids and shoal waters from Lake St. Francis to Lake St. Louis; and (e) the Lachine Section including Lake St. Louis and the rapids and shoals to Montreal Harbor, a distance of 23 miles.

4. The St. Lawrence River is unique among the rivers of the world in that the tremendous storage capacity of the lakes regulates the flow

to an unusual extent. The average monthly outflow of Lake Ontario from 1860 to 1940 was 237,000 cfs, the minimum 144,000 cfs, and the maximum 314,000 cfs. The drainage area above St. Regis, located at the foot of the International Rapids Section, is approximately 303,000 square miles, of which 95,000 square miles are water surface. This large discharge and drainage area make the St. Lawrence one of the larger rivers of the world.

International Rapids Section

5. The International Rapids Section of the river (shown on plates 2 and 3) contains numerous islands which divide the river into many crooked and irregular channels. The section consists mostly of rapids and reaches of swift but smoothly-flowing water. Velocities are generally high and water-surface slopes steep. The total fall for this 46-mile reach is approximately 92 feet.

6. The steep slope starts at the head of Galop Island. The channels past Galop Island are called the Galop Rapids, the north channel being called the Canadian Galop Rapids, and the south channel the American Galop Rapids. Below Galop Island the river flows through an irregular channel with varying reaches of swift and relatively slower flows to the Rapide Plat opposite the upper end of Ogden Island. Most of the fall in the Ogden Island reach occurs in the Rapide Plat to the north of Ogden Island, while most of the fall in the channel to the south takes place at Waddington near the lower end of the island where the channel is obstructed by a causeway and the remains of an old dam. Between Ogden and Chrysler Islands, the river is divided by a series of islands. Below

Chrysler Island, the channel is unobstructed to Steens and Cat Islands near the head of Croil Island. Croil Island and Long Sault Island divide the river into two channels. The largest rapids in the International Section is the Long Sault, which begins near the middle of Long Sault Island and ends at the foot of that island. The Long Sault south channel is a series of minor rapids throughout its entire length. Near the head of Long Sault Island, a weir has been constructed across the channel which diverts approximately 25,000 cfs through a canal to the Grass River below Massena. Below Long Sault Island, the main channel (Barnhart Island south channel) is a section of swift water. The final rapids occurs at the lower end of the Barnhart Island north channel. Below Barnhart Island, the river flows swiftly to the head of Cornwall Island where it is again split into two channels which enter Lake St. Francis near the foot of Cornwall Island. Of the total fall of 92 feet in the International Rapids Section between Chimney Point and Lake St. Francis, 10 feet are concentrated in the Galop Rapids, 12 feet in the Rapide Plat, 29 feet in the Long Sault Rapids, and 9 feet in the Barnhart Island north-channel rapids.

Navigation

7. A 14-ft navigation channel has been developed through the International Rapids Section on the Canadian side of the river; lateral canals, by-passing the steeper portions of the river, were constructed by the Dominion of Canada early in the present century. The canal by-passing Galop Rapids extends downstream a distance of more than seven miles to the town of Iroquois. The water surface in the canal is

maintained by Lock 25, Lock 27 (a guard lock), and Lock 28. Lock 28 is provided for downstream traffic which leaves the canal and proceeds downstream in the river past Cardinal Point to Lock 24 at the head of the Morrisburg Canal. Upstream navigation enters the canal at Lock 25 which is located at Iroquois. Near the head of Ogden Island, the Morrisburg Canal by-passes the Rapide Plat and the swift water at Morrisburg; the Farren's Point Canal carries navigation around the swift water at the head of Croil Island; and the Cornwall Canal system by-passes the Long Sault Rapids and the swift water downstream to below Cornwall. The controlling dimensions of the locks are: length 252 feet, width 44 feet, and depth over sills 14 feet.

St. Lawrence River Project

8. The St. Lawrence River Project consists of those proposed improvements in the International Rapids Section which would be constructed by the United States. This 46-mile section is one of the major obstacles to opening the Great Lakes to ocean commerce and is potentially one of the largest possible hydroelectric developments in the United States; therefore, the St. Lawrence Project is a combined navigation and hydroelectric-power development. The main features of the project are:

a. A dam in the Long Sault Rapids at the head of Barnhart Island, and a dam and two powerhouses, one on either side of the International Boundary at the foot of Barnhart Island.

b. A control dam in the vicinity of Iroquois Point.

c. A side canal with one lock on the United States mainland to carry navigation around the control dam, and a side canal with one

guard gate and two locks on the United States mainland south of Barnhart Island to carry navigation from above the Long Sault Dam to the river at the head of Cornwall Island. All locks are to provide a 30-ft depth over the sills and are to be of the same general dimensions as the Welland Ship Canal.

d. Dikes or levees, where necessary, on the United States and Canadian sides to retain the pool level above the Long Sault Dam.

e. Necessary channel enlargment to provide a 27-ft depth from the head of Galop Island to below Lotus Island, and to provide velocities in the navigation channel which will not be excessive for navigation.

f. Such channel enlargement between Lotus Island and the control dam and from above Point Three Points to below Ogden Island, as necessary to give a maximum mean velocity in any cross section not exceeding 2.25 ft per sec (to permit the formation of an ice cap) at the discharge and stage to be permitted on the first of January of any year under regulations governing the control of outflows and levels of Lake Ontario.

g. The necessary railroad and highway modifications on either side of the International Boundary.

h. The necessary works to permit the continuance of 14-ft navigation on the Canadian side around the control dam and from the pool above the Long Sault Dam to connect with the existing Cornwall Canal during the construction period.

9. Regulation Method No. 5. The St. Lawrence River above the Galop Rapids Section may be considered properly as an arm of Lake Ontario. The water surface through this reach is nearly flat; its elevation never varies greatly from that of the lake. The first sharp drop in the flow

line occurs at Galop Island, where the river falls over a natural ledge of hard rock opposite Adams Island on the Canadian side and near the lower end of Galop Island on the American side. Thus, this ledge of rock which forms the Galop Rapids also exercises control over the elevation of and the discharge from Lake Ontario. All plans of improvement considered for the Galop Rapids reach contemplate the removal of this control in order to provide the maximum head for power development and to satisfy navigation requirements, and the transfer of lake-level control to a dam to be constructed downstream. The natural control at Galop Island has resulted in certain variations in Lake Ontario levels to which all improvements bordering the lake have adjusted themselves. It would not be possible to change these normal levels appreciably without causing considerable damage to riparian property. Also, it would be desirable to maintain approximately the same seasonal variations in discharge so as not to affect appreciably the present river characteristics and lake-level fluctuations. It would be particularly desirable that the normal minimum discharge not be decreased, due to possible adverse effects on water levels in Montreal Harbor and reduced power benefits. Any increase in the maximum spring discharge would be undesirable, due to aggravation of flood problems downstream and to the necessity for larger cuts to obtain navigable velocities. Furthermore, it would be undesirable to increase the winter flow appreciably because larger cuts would have to be made to insure the formation of an ice cover. It was recognized, therefore, early in studies of this project that if the natural control at Galop Island were to be removed and a variable control in the form of a dam substituted, operating rules would have to be established for the

dam which would insure the same general seasonal variation in outflows and lake levels as exist at the present time. The subject of operating rules has been given much study by all concerned with this project over a period of many years. Several regulation methods have been proposed, each method being based on the hydrological records from 1860 to the present. The method found to be the most satisfactory was the one developed by the Canadian Department of Transport and designated "Method No. 5." This method was designed to meet the following requirements:

a. To keep the fluctuations of the levels of Lake Ontario within the levels that would have resulted in the past assuming a continuous diversion of 3200 cfs at Chicago and present outlet conditions.

b. To maintain without impairment the low-water levels of Montreal Harbor.

c. To maintain low flows during the winter period, December 15 to March 31, in order that the difficulties of winter power operation not be aggravated.

d. To maintain flows during the first half of April no greater than would naturally occur, in order to avoid the danger of aggravating the spring rise during the breakup of the ice below Montreal.

e. To avoid any material increase in the amount and duration of the high discharges during May, in order not to aggravate the high water levels in Lake St. Louis during the Ottawa floods.

f. To keep the fluctuation in monthly mean discharges within the limits which have existed in nature.

g. To hold back the natural excess outflow during the early summer months in order to raise during that period the ordinary levels

of Lake Ontario.

h. To secure the maximum dependable flow throughout the year for power operation.

10. Velocity criteria for the Galop Rapids improvement. Any channel enlargement in the Galop Rapids Section must be dimensioned in such manner that velocities will not be excessive for navigation. This necessitated the definition of "excessive velocities". The International Agreement of 19 March 1941 provided for:

> ". . . channel enlargement from the head of Galop Island to below Lotus Island designed to give a maximum velocity in the navigation channel not exceeding 4.0 ft per sec at any time."

In the application of this criterion to the design of the project, it was agreed between engineers of the Canadian Department of Transport and the District Engineer, St. Lawrence River District, CE, that velocities in excess of 4.0 ft per sec would be allowed to occur in the navigation channel during 3 per cent of the navigation season, provided that the maximum never exceeds 4.5 ft per sec during that period. The term "velocity" has been defined as the velocity obtained by dividing the discharge through the channel by the cross-sectional area of the channel. In view of the fact that the velocities to be obtained from the model study were to be measurements of the mean velocity in the vertical at specific locations (spot velocity), a further assumption was made as to the interpretation of the modified criterion, that most of the spot velocities are to be under 5.0 ft per sec with none over 5.25 ft per sec. This clarification was designed to facilitate the analysis of data to be obtained from the model and is an interpretation of the criterion

modification which was agreed to by engineers concerned. The maximum allowable "spot velocity" of 5.25 ft per sec approximates very closely an average velocity of 4.50 ft per sec, based on the assumption that the maximum velocity in any stream cross section is usually around 115 per cent of the average.

11. Original Galop Rapids improvement plans. The Galop Rapids Section includes that portion of the river which lies between Chimney Point and a point a short distance below Lotus Island and is listed as Feature No. 1 in the 1942 Project Report. Two different plans were developed, prior to the undertaking of the model study, for the fulfillment of the dimensional and velocity requirements set up in the International Agreement of 1941. The general features of these two plans were:

a. The "Recommended Plan" or "Revised Canadian Plan" (shown on plate 14) involved: (1) the development of a navigation channel from Chimney Point, through the Galop Island south channel, between Baycraft and Lalone Islands, and extending to below Lotus Island; and (2) the excavation of a channel (referred to hereinafter as the "hydraulic channel") through Galop Island and the removal of Gut Dam and Locks 27 and 28 to redistribute the river discharge and reduce velocities in the navigation channel, and the excavation of an auxiliary hydraulic relief channel between Lalone Island and the American mainland to reduce the discharge and velocity in the navigation channel passing Cardinal Point.

b. The "Alternate Plan" (shown on plate 64) involved the development of a navigation channel along a relatively straight course from Chimney Point through Galop Island to below Lotus Island. Dikes

would be provided along both sides of the navigation channel above and below Galop Island to prevent cross currents and to increase the friction loss in the channel, thereby increasing the flow in the outside channels and thus lowering velocities in the navigation channel. To more fully utilize the capacity of the Galop Island south channel an auxiliary hydraulic channel was provided by enlarging the existing Lalone and Lotus Island south channel.

PART III: THE MODEL

12. Need for the model. During the period from October 1940 to June 1942, the St. Lawrence River District at Massena, New York, conducted extensive studies of all phases of the St. Lawrence Project. During the preliminary studies of the design for the principal or critical reaches, it was realized that because of the complex nature of the problems involved, hydraulic model studies would be necessary to determine the optimum design in most instances, particularly in view of the importance of the project and the great expenditures involved. It was the consensus of the American and Canadian engineers concerned that a model study of the Galop Rapids section was exigent. In this section the uncertainties in certain of the hydraulic data and the assumptions which had been necessary in the basic computations made it particularly desirable to check the proposed designs. The two basic plans, the "Recommended" and the "Alternate," included several features which merited closer study than was possible by hydraulic computations. In the case of the Recommended Plan it was desired to determine the adequacy of channel cuts in critical reaches, the magnitudes and distributions of velocities, the water-surface profiles, and the distributions of discharges among the various channels. It was also desirable to determine the adequacy of the hydraulic channel for navigation purposes, and the effectiveness of a cut between Chimney and Drummond Islands. In the case of the Alternate Plan, even more intensive study by means of model tests appeared desirable. In addition to most of the questions which appeared pertinent to the Recommended Plan, the Alternate Plan

posed additional problematical points in connection with dike arrangements. The question of whether dikes would be required above Galop Island to prevent cross currents which would hamper navigation could be answered best by model studies. In both plans the determination of the most suitable locations for the spoil areas required study in the model, since information was required as to distributions of velocities, deadwater areas, and eddies. The solution of the problem in the Galop Rapids Section was complicated by the fact that it would be necessary to carry out the construction program without materially affecting Lake Ontario levels or discharges and without interfering with navigation in the Galop Canal. An additional purpose of the model was to make a complete investigation of the hydraulic characteristics of the channels in their natural states, in order to check the assumptions made in previous hydraulic computations and to provide data for future hydraulic computations.

13. Scale ratios. The Galop Rapids model was constructed to linear scale-ratios, model-to-prototype, of 1:400 horizontally and 1:80 vertically, with a resultant geometric distortion of 5. The selection of these scale ratios was based upon the following considerations: (a) previous experience with similar problems indicated that such a model would furnish satisfactory solutions of the problems presented, and would be considerably more economical to construct than an undistorted model; (b) known physical and hydraulic characteristics of the Galop Rapids channels indicated that such a model would accurately reproduce (to proper Froudian scale relationships) the proper roughness factors and hydraulic characteristics of the prototype without appreciable alteration

of the cross-sectional areas of the channels. Scale ratios, model-to-prototype, for the transference of model data to prototype equivalents in accordance with Froudian relationships are presented in the following tabulation:

Dimension	Relationship
Horizontal	L_r (selected) = 1:400
Vertical	D_r (selected) = 1:80
Slope	$S_r = D_r/L_r$ = 1:0.2
Area (cross-sectional)	$A_r = L_rD_r$ = 1:32,000
Velocity	$V_r = D_r^{1/2}$ = 1:8.94
Discharge	$Q_r = L_rD_r^{3/2}$ = 1:286,218
Hydraulic radius	R_r (computed for each section)
Roughness (Manning's)	$N_r = R_r^{2/3}L_r^{-1/2}$ = 1:1 (approx.)

14. Physical description of the model. The model was approximately 130 ft long, and about 36 ft wide at its widest point. It reproduced the St. Lawrence River from Ogdensburg, just below the mouth of the Oswegatchee River, to Sparrowhawk Point, below Lotus Island (see frontispiece) and was designed to study Feature No. 1 of the St. Lawrence River Project. The model was of the fixed-bed type, molded of concrete to plotted fiber-board templets. Certain portions of the model were originally constructed of removable and interchangeable concrete blocks, so that existing river conditions or either of the two originally proposed improvement plans could be installed without the necessity for breaking out and remolding sections of the model. However, during operation of the model changes in the original plans became so extensive that the use of concrete blocks was abandoned in favor of a soil-cement

mixture in which the desired channel changes could be carved as necessary. This soil-cement mixture was soft enough to permit carving to any desired configuration, yet hard enough to prevent deformation or erosion, and proved to be ideal for making minor alterations in the model.

Model appurtenances

15. Water supply. The model was located near an artificial lake from which water was pumped to supply the model. A venturi meter was used to measure the inflow to the model. The water after passing through the model was returned to the lake by gravity flow.

16. Tailwater control. To reproduce the backwater effect of the river and structures below Sparrowhawk Point, an adjustable steel tailgate was placed at the lower end of the model. This tailgate was in effect an adjustable horizontal overflow weir and was equipped with a gage to facilitate adjustment.

17. Gages. All gages in the Galop Rapids Reach maintained by the Department of Transport, together with the Ogdensburg gage which is maintained by the U. S. Lake Survey, were installed in the model as shown on plate 4 except the Ogdensburg gage which is shown on plate 2. In the model these were manometer-type gages which were read from a central control pit. Although these gages were sufficient for use as controls, they were too widely spaced for the development of detailed water-surface profiles. Consequently, auxiliary gage points were established along the shore lines at intervals corresponding to 500 ft in the prototype and water-surface elevations at these points were read with a portable point gage.

18. Discharge interceptors. To intercept and measure the flow in each of the channels, a network of pipes connected to a V-notch weir was installed. Discharge interceptors were provided for the Galop Island south channel, the proposed cut through Galop Island, the channel between Galop and Adams Islands, Galop Island north channel, Dead Man's Rapids, and Lalone and Lotus Island north channel. Flow was measured in only one channel at a time, and was accomplished by completely blocking the channel and passing the water through the interceptor to the measuring weir. To secure the proper flow, a regulation valve at the intake to the weir box was manipulated until water levels both above and below the interception point were exactly the same as under normal flow conditions, the loss of water through the interceptor being compensated by placing artificial obstructions in the lower reaches of the other interconnecting channels.

19. Velocity measurements. Velocities were measured in the model by timing the travel of floats* through a distance of 1 ft (400 ft, prototype), the point at which velocities were to be determined being at the center of this 1-ft range. The floats were required to pass within not more than 2 inches (67 ft, prototype) of the measurement point in all cases. Since the manual timing of floats with a stop-watch was found to produce somewhat inconsistent results, an electronic float-timer was developed to eliminate this error and improve the accuracy of measurements.

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* Different types of floats were used for different purposes during the testing program. These varied from staff floats submerged to a depth of 0.9 of the total water depth to floats which registered only the surface velocity. The type used is described in each case hereinafter.

PART IV: MODEL VERIFICATION

Introduction

20. The "verification" of this type of hydraulic model is accomplished by careful adjustment of the channel roughness until an accurate and detailed reproduction of all observed hydraulic phenomena of the river is obtained. The results obtained at the culmination of this hydraulic adjustment phase demonstrate the degree of accuracy and reliability which can be expected of tests of the proposed plans of improvement. The verification of the Galop Rapids was particularly important since a major portion of the natural channel was to remain undisturbed by the installation of any of the various plans of improvement.

Basic Prototype Data

21. The verification of the model was based upon an accurate reproduction of the following prototype data:

a. Standard low-water profile for a discharge of 197,000 cfs, St. Lawrence River District Office, Massena, New York, drawing SX-1-532/2 and 3.

b. The June 1943 high-water profile obtained by the New York District Office and shown on New York District drawings 9396/1, 2, and 3.

c. Rating curves for the International Rapids Section, St. Lawrence River District Office, Massena, New York, drawing SX-1-532/10.

d. Discharge measurements, showing distribution of flows, made by the Hydroelectric Power Commission of Ontario during 1918-19-20.

e. Surface currents and velocities shown on St. Lawrence River District Office, Massena, New York, drawing GC-1-531/1.

f. Surface currents sketched by Mr. D. C. Bondurant and Captain G. B. Fenwick during their inspection trip to the St. Lawrence River, 1-15 June 1943.

g. Information as to the characteristics of the river bottom and details of the surface flow pattern, furnished by Mr. Ed LaFlair, a commercial fisherman from Ogdensburg, New York.

A brief discussion of each of the above items is presented in the paragraphs which follow.

22. Standard low-water profile. The standard low-water profile was developed in 1941-42 by the Massena, New York, Office through a comprehensive study of all data available at that time. This profile, applied to the gage equations of the Lake Survey, gave an average discharge of 197,000 cfs. The following data were used in preparing this profile: gage records and rating curves from the U. S. Lake Survey, the Canadian Department of Transport, and the Hydroelectric Power Commission; maps from the Canadian engineers showing water-surface elevations observed in 1919, 1920, and 1921 when the river discharged from 210,000 to 220,000 cfs; and water-surface elevations observed by the Massena Office in 1941 when the river was discharging approximately 220,000 cfs. The low-water-datum elevations given by the U. S. Lake Survey, and those obtained from the Canadian Department of Transport rating curve at Lock 28, were used as control points in establishing the low-water profile. Other points were obtained from secondary rating curves. The water-surface elevations mentioned above were then used to construct the

profile between rating curve points. This low-water profile is shown on plate 5; the center-line stationing used in developing the profile is shown on plate 4.

23. High-water profile. During the summer of 1943, the St. Lawrence River reached a near-record high stage, at which time the New York District obtained detailed water-surface elevations for the entire International Rapids Section. Elevations were obtained along both banks and around most of the islands. The actual work on the Galop Rapids Section was done during the period 4 June-2 July 1943. The hourly stage hydrograph for the Ogdensburg gage during this period was obtained from the U. S. Lake Survey Office, Detroit, Michigan. With this information, personnel at the Experiment Station applied the necessary minor adjustments to the observed water-surface elevations to make them comparable to a stage of 247.75 (the June mean stage) at the Ogdensburg gage. The high-water profile shown on plate 5 was then prepared using the center-line stationing shown on plate 4. From the U. S. Lake Survey discharge equation for the Ogdensburg gage, the river discharge corresponding to this profile was determined to be 295,700 cfs.

24. Rating curves for the International Rapids Section. These curves represent the results of a comprehensive study of all available hydraulic data. However, with the exception of Lock 27, Lock 28, and Ogdensburg, these curves represent stages for a range of discharges only between 197,000 and 247,000 cfs.

25. Discharge measurements. The Hydroelectric Power Comission of Ontario during 1918, 1919, and 1920 made a series of discharge measurements to study the distribution of flow among the various secondary

channels. Although the method of measurement is not known, an excellent degree of accuracy is indicated, since the measured flow through the Lalone and Lotus Island south channel checked within 2 per cent the discharge computed by subtracting the sum of the discharges of the Galop-Dixon, Dixon-Sears, and Dead Man's Rapids channels from the discharge of the Galop Island south channel. The results of these discharge measurements are shown on plate 6.

26. Surface currents. During the early adjustment phase of the model study, differences were found between the current directions in the model and those indicated on St. Lawrence District drawing GC-1-531/1. Early in June 1943 an inspection trip was made to the St. Lawrence River by Mr. V. R. Stirling, Engineer, and Mr. D. C. Bondurant, Engineer, formerly connected with the Massena, New York, Office and Captain G. B. Fenwick of the Experiment Station. They discovered several discrepancies in the flow patterns as depicted on the drawing, and also found that numerous eddies and other local flow characteristics had not been shown. At the suggestion of these engineers, the New York District Engineer arranged for Mr. Ed LaFlair to spend several weeks at the Experiment Station as a consultant during the model verification. The detailed surface-current map shown on plate 7 was prepared, utilizing Mr. LaFlair's intimate knowledge of the river bed and currents and the information gained during the June inspection trip mentioned above.

27. Velocities. The velocities obtained by the Massena Office were surface velocities measured by means of a tachometer on a survey boat. The boat was held in position by varying the speed of the screw so that the tachometer reading could be used as an index of current

velocity. The accuracy of this method of measurement is dependent not only upon the accuracy of the tachometer but also upon the accuracy with which the operator maintained and recorded his position. These velocities, given in miles per hour, are shown on plate 7.

Procedure of Model Verification

28. Model configurations. That portion of the model between Chimney Point and Sparrowhawk Point was constructed in accordance with the hydrography and topography shown on the Massena Office drawings SC-1-534/1, 2, and 3. The reach between Chimney Point and Ogdensburg was molded to soundings furnished on sheet 11 of the Survey of the St. Lawrence River, made by Benjamin D. Bell, 1937-1938. The Department of Transport gages within the model limits were located in accordance with Canadian drawing 2136, sheet 1.

29. Model operation. In all operations to adjust and verify the model to the high- and low-water profiles, the water level below Lotus Island (gage 6) was held to the prototype elevation corresponding to the discharge being used. The water-surface profiles throughout the model were then adjusted, by the trial and error method, by the application of stucco and gravel roughness until the model flow lines corresponded to those observed in the prototype. The application of bottom roughness was governed not only by its effects on the water-surface profiles, but also by its effect on the distribution of flow and the surface-current pattern. The water-surface elevations were measured by means of the Department of Transport gages reproduced in the model and supplemented by numerous intermediate gage points which were so placed as to define

clearly the water-surface profiles between the permanent gages. The distribution of flow was obtained through the model discharge interceptors. Surface-current directions were obtained by photographing and sketching the paths followed by confetti. Surface velocities were obtained by timing the passage of numerous pieces of confetti over 1-ft ranges.

Results of Model Verification

30. Water-surface profiles. The model reproductions of the standard low-water profile and the high-water profile are shown on plate 5, together with corresponding prototype profiles. During the early adjustment phase of the model study, it was found that the two prototype profiles were not exactly compatible; that is, with any one channel roughness the model could not reproduce exactly both profiles. It was evident, therefore, that there existed some error in the furnished prototype discharge data for either the low or the high flow (this was later found to be the case). In view of the fact that the higher discharge was arrived at by an extrapolation of a discharge equation prepared from data obtained at much lower discharges, it was considered most probable that the error lay in the higher discharge figure. However, the model roughness was so adjusted as to divide the error between the low and high flows, with the result that the model low-water profile was approximately 0.25 ft (prototype) too high, while the high-water profile was low by approximately the same amount. This point was discussed during a conference at the Experiment Station with the District Engineer and certain of his assistants, and it was the consensus of the engineers present

that the amount of error involved in the results of the model study is so small as to be negligible.

31. Discharge distribution. It is significant that the correct distribution of discharges was automatically obtained in the model by the adjustments described in the preceding paragraph to verify the model water-surface profiles. The distribution in the river (obtained by averaging the Power Commission measurements, which were made when the total river flow was around 230,000 cfs), together with corresponding figures obtained with a simulated flow of 230,000 cfs in the model, is shown in the following tabulation:

Channel	Prototype	Model	Difference
Galop Island south	49.0%	48.0%	-1.0%
Dead Man's Rapids	29.8	28.5	-1.3
Lalone and Lotus Island north	90.4	90.9	-0.5

Subsequent testing at other discharges, however, showed that a straight-line variation with discharge occurred in the percentile discharge distributions. Plate 6 shows the flow-distribution curves, to which have been added plots of the Power Commission's actual measurements in the river. It will be noted that an even closer verification is indicated by these data than by the above tabulation. (Since the flow through the three channels of Dead Man's Rapids and that through the Galop-Dixon-Sears double channel were each made as one measurement in the model, no attempt has been made to correlate the individual channel measurements of the river with the model curves.)

32. Surface currents. A comparison of the river surface currents (plate 7) with those obtained in the model (plate 8) shows an excellent model reproduction of the prototype flow pattern. This may be noted

especially in the reproduction by the model of even minor surface current eddies. Only very minor variations from the prototype occurred, the one discrepancy of any appreciable extent being at the lower end of Tick Island. The prototype sketch shows a current breaking directly from the lower end of Tick Island back toward the end of Galop Island with no eddy present, while the model sketch shows the breakpoint several hundred feet below Tick Island with an eddy at the foot of the island. This discrepancy was of minor significance, due to the low velocities and shallow depths involved.

33. Velocities. Plates 7 and 8 also show the results of spot surface-velocity measurements in the prototype and model, respectively. A generally close agreement was obtained with a majority of the furnished prototype velocities. In view of the methods used in obtaining the prototype velocities (described in paragraph 27 above) it is possible that some of the discrepancies could be partly attributable to the lack of precision in the method of obtaining and locating velocities in the prototype.

Discussion of Verification

34. The model verification as reported herein was accepted by the District Engineer and other interested engineers as being entirely satisfactory. The degree of accuracy obtained was well within the allowable limits of any of the basic prototype data, and was believed to be entirely sufficient for the solution of the problems to be encountered in future model testing. Investigations of the existing river rating curves strengthen considerably the reliability of the model reproduction of the water-surface profiles. In paragraph 30 it was noted that the

high- and low-water prototype profiles were not exactly compatible, and that the model was adjusted to produce a low-water profile approximately 0.25 ft higher than the prototype profile, and a high-water profile approximately 0.25 ft low. Although this small discrepancy was accepted as negligible, it was felt by engineers of the Experiment Station that error lay, not in the model, but rather in the reliability of certain elements of the furnished data. This led to considerable investigation of the rating curves used for the Ogdensburg gage, which disclosed that the prototype high- and low-water profiles had been developed on different datum planes and that there was a difference of 0.28 ft between the two planes. The discovery of this discrepancy prior to completion of the model verification would have resulted in closer model reproductions of the water-surface profiles than were actually obtained.

35. The model also proved useful during the adjustment phase in leading to the correction of other small but significant errors in prototype data. With the model channels molded to the configuration of the furnished river surveys, it was found impossible to reproduce correctly either the water-surface profiles or the distribution of discharges in the vicinity of the upstream end of the Galop Island north channel. Following an investigation of the hydrographic maps from which the model was molded, errors of from 1 to 3 ft in depth at certain control points were discovered. After corrections were applied to the model hydrography, accurate reproductions of water-surface profiles and flow distributions were readily obtained. In another instance where difficulty was experienced in obtaining the correct surface-flow pattern between Lalone and Lotus Islands, additional soundings were requested between Lotus Island

and the American shore. Correction in the model of the errors thus discovered in the original soundings resulted in the correct reproduction of the flow pattern.

PART V: MODEL BASE TESTS

36. Introduction. Following the verification of the model a series of tests was conducted and model data collected to supplement known data and to extend the present knowledge of the hydraulics of the river over a wider range of flow conditions, in order to provide a sounder basis for possible future computations. The "base tests" (a term applied to tests of existing prototype conditions) were conducted with the river in natural conditions for discharges of 180,000, 255,000 and 310,000 cfs -- these discharges having been designated as the minimum, mean, and maximum discharges of the St. Lawrence River.

37. Data obtained. The model data obtained for these discharges consisted of the following items:

a. Water-surface profiles (shown on plate 9).

b. Distributions of discharge (shown on plate 10).

c. Surface-current directions (shown on plates 11-13 and photographs 7-14).

d. Velocities (shown on plates 11-13).

The paragraphs below present a discussion of each of these items.

38. Water-surface profiles. These profiles (plate 9) were developed using the center-line stationing (plate 4) adopted by the St. Lawrence River District. The elevation of any point on the profile refers to a point on the bank at right angles to the channel center line; profiles for the right and left banks, where different, are shown as solid and dashed lines, respectively. The water-surface elevation at gage 6 for each discharge was obtained from an extrapolation of the

furnished prototype rating curve for this gage. For the discharge of 180,000 cfs, the curve was extended downward as a straight line, using as a guide the lower portion of the curve; for the discharges of 310,000 cfs and 255,000 cfs the curve was extended upward, from the last given point (247,000 cfs), through the elevation observed at gage 6 for the high-water survey of June 1943, when the discharge was rated as 295,700 cfs.

39. Distribution of discharge. The method of obtaining discharge-distribution data has been described in paragraph 18. Plate 10 shows the discharge distribution for the maximum, minimum, and mean discharges, the data actually measured in the model being shown as solid lines and the data deduced therefrom as dashed lines. In addition to the flow-distribution data obtained for the three base-test discharges, similar data on the discharge used in the verification tests (230,000 cfs) were also used in this plot. It will be noted that a straight line variation was obtained in each case. An increasing percentile discharge through the Galop Island south channel is indicated with an increase in the total river flow. A decreasing percentile discharge may be noted for the Lalone and Lotus Island north channel with an increase in the total river flow. The percentile flow through Dead Man's Rapids remained almost constant for all discharges with only a slight increase for an increasing total discharge. This indicates an increasing capacity of the Lalone and Lotus Island south channel as the river discharge increases. With these three discharges known, it is possible to deduce the flow in the other channels. The flow between Dixon and Galop Islands has been combined with the flow between Dixon and Sears Islands, since measurements by the

Hydroelectric Power Commission of Ontario in 1921 indicate that only 2 per cent of the total river flow was carried by the Dixon-Sears channel.

40. Surface-current directions. Surface-current directions for the three discharges were obtained in the model by sketching and photographing the paths followed by confetti. These data are shown on plates 11, 12, and 13 and photographs 1-8. The photographs were taken for a river discharge of 255,000 cfs.

41. Velocities. Plates 11, 12, and 13 also show velocities measured in the model during the three base-test flows. These velocities were measured by timing the passage of staff floats over 1-ft ranges; the average ratio of float length to depth of water was about 0.75. Each velocity shown is a mean of numerous measurements at that point. Measurements with a pitot tube at 0.6 depths checked these staff-float velocities.

PART VI: THE RECOMMENDED PLAN

Description of the Recommended Plan

42. The Recommended Plan for the improvement of the Galop Rapids Section of the St. Lawrence River was based upon the concept of establishing a navigation channel through the Chimney Point channel and the Galop Island south channel and reducing the flow through this channel by constructing a relief cut (hereinafter called the "hydraulic channel") through Galop Island. The plan consisted of the following features, which are shown in detail on plate 14:

a. Navigation channel. The navigation channel required excavation in two localities: (1) excavation to grades of 212 and 214 over a 1400-ft width through the constricted reach between Chimney Point and Chimney Island; and (2) excavation through the Galop Island south channel from just above Butternut Island to deep water just below Lotus Island to provide a channel 600 ft wide from its upper end to about the middle of Lalone Island and flared below this point; excavation of this channel was to a grade of 214, except that all rock excavation was carried to a grade of 211. A small cut to grade 230 was provided at the south end of Butternut Island to improve flow conditions.

b. Hydraulic channel. To secure the necessary reduction of discharge and velocities in the navigation channel, the hydraulic channel was excavated 850 ft wide to a grade of 216. This channel extended through Galop Island and across the ends of Dixon and Sears Islands down to Cardinal Point. A slightly flared entrance was excavated to a grade

of 220 from the head of Galop Island to the 220 contour above and opposite Tick Island. The north limit of excavation was flared slightly across Cardinal Point to provide a 2000-ft channel between Lalone Island and Cardinal Point. During the construction period, the hydraulic channel would be utilized to accomodate the normal flow of the Galop Island south channel during the cofferdamming and excavation in the latter channel.

c. Velocity reduction opposite Cardinal Point. In order to reduce velocities between Cardinal Point and Lalone Island, a relief cut was excavated to a grade of 214 over a 500-ft width through the channel between Lalone Island and the American mainland.

d. Removal of existing structures. Spencer Island Pier was entirely removed, for the purpose of improving flow conditions in the navigation channel opposite Chimney Point. Gut Dam (between Galop and Adams Islands) and Locks 27 and 28 were removed, in order to increase the capacity of the Galop Island north channel and thus reduce velocities in the navigation channel. Lock 26 on the old canal at Cardinal Point was removed.

Model Tests of the Recommended Plan

Scope of tests

43. The initial model tests of the Recommended Plan were made for the purpose of providing a check on the hydraulic computations on which this plan was based, and of providing an indication as to the extent of the modifications which might be required in the various features of the plan.

Roughness of excavated channels

44. Prior to model testing of the Recommended Plan, the hydraulic channel was installed and a series of tests was conducted to secure the proper surface roughness. Since a roughness coefficient (Manning's "n") of 0.020 had been used in the design computations for excavated areas, especial efforts were made to obtain a corresponding value in the model. Also, in view of discussions which had arisen as to whether this assumed value was correct, and as to the possible hydraulic effects of variations in the surface roughness, tests were made of the effects of varying the roughness coefficient of the hydraulic channel from 0.016 to 0.026. Plate 16 shows a plot of three water-surface profiles from Ogdensburg to below Lotus Island through the hydraulic channel, one for a roughness coefficient of 0.016, one for 0.026, and one for 0.021. With the exception of surface roughness, conditions were identical for all three tests: discharge 255,000 cfs, hydraulic channel open, remainder of river in natural state, water surface below Lotus Island maintained at the fixed elevation found necessary to obtain an elevation at Ogdensburg comparable with Method No. 5. The results of these tests demonstrate that surface roughness can be varied considerably in this type of channel with only very minor hydraulic effects; that is, that actual surface roughness constitutes a very minor part of the total resistance to flow as compared with the effects of islands, shoals, channel sinuosities, and irregularities in the bed and banks.

45. The roughness value corresponding to a prototype "n" of 0.021 was used in the hydraulic channel in subsequent tests of the Recommended Plan. This same surface finish was also placed on all other excavated

surfaces. The roughness of all natural channel surfaces was identical with that found necessary in the verification of the model.

Method of operation

46. The Recommended Plan was tested for minimum, mean, and maximum discharges. In each test, the governing water-surface elevation was that elevation at Chimney Point which would be obtained with the lowest Lake Ontario Level indicated by "Method No. 5." The control elevations furnished the Experiment Station for Chimney Point and Lake Ontario for the three discharges used were as follows:

Discharge in cfs	Lake Ontario Elevation	Chimney Point Elevation
310,000 (Max)	246.5	244.27
255,000 (Mean)	246.0	244.40
180,000 (Min)	244.0	242.93

The tailwater elevation below Lotus Island (gage 6) was manipulated in each case until the above elevations were obtained at Chimney Point.

Data obtained

47. The data obtained during the testing of the Recommended Plan consisted of water-surface profiles, discharge distributions, velocities, and surface-flow patterns. The methods of obtaining these data have been explained in Part III of this report.

Results of tests (compared with computations*)

48. Water-surface profiles. Plate 15 shows the new center-line

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* The computed results mentioned herein were obtained from Appendix A-2, General Data, St. Lawrence River Project, Final Report of 1942.

stationing which was developed by the Experiment Station for use in observing and plotting water-surface profiles for tests of the Recommended Plan; the center-line stationing used in the base tests is also shown, and equations between the two are given. Water-surface profiles for the minimum, mean, and maximum discharges are shown on plate 17. The profiles for the Galop Island north channel represent elevations along the left bank of the river. A comparison of the model results with computed results for a discharge of 310,000 cfs is furnished by the following figures:

	Computed* Elevation		Model Elevation
	Canadian	O.C.E.	
Chimney Point	244.27	244.27	244.24
Below Lotus Island	242.00	242.75	242.48
Drop in feet	2.27	1.52	1.76

The discrepancy between the results as shown may be attributable in part to the roughness values assumed in the basic computations.

49. Discharge distribution. A comparison of discharge distributions for a total river flow of 310,000 cfs, as obtained in the model and as computed, is shown by the following tabulation:

Channel	Computed* Discharge	Model Discharge
Galop Island south	124,000 cfs	140,000 cfs
Galop Island Cut Hydraulic	119,000 cfs	108,000 cfs
Galop-Adams	7,000 cfs	10,000 cfs
Galop Island north	60,000 cfs	52,000 cfs
Total	310,000 cfs	310,000 cfs

* The computed results mentioned herein were obtained from Appendix A-2 General Data, St. Lawrence River Project, Final Report of 1942.

As in the case of discharge distribution in the model base tests, it will be noted from plate 18 that a straight-line variation of percentile discharge with total river discharge was obtained in tests of the Recommended Plan. An increasing percentile discharge occurred through the navigation channel with increasing total river flow. A fairly constant percentile discharge occurred through north channel and a decrease through the hydraulic channel for increasing river discharges. The flow interceptor in the model was not in a proper position for determining accurately the discharge north of Lalone Island; however, approximate measurements indicated that the Lalone Island south channel carried a greater discharge than was indicated by the hydraulic computations, a considerable portion of this flow being returned to the navigation channel through the Lalone and Lotus Island channel.

50. Velocities. Plates 19, 20, and 21 show velocities observed in model tests of the Recommended Plan. According to Office, Chief of Engineers computations, the maximum velocity in the navigation channel (computed flow 124,000 cfs) was found to be about 4.67 ft per sec at a point near the lower end of Galop Island. According to these computations, the effective area at this section must have been $\frac{124{,}000 \text{ cfs}}{4.67 \text{ ft/sec}} = 26{,}550$ sq ft. Assuming that this same area would be obtained for the discharge of 140,000 cfs obtained in the model, the average velocity at this critical section would have been $\frac{140{,}000 \text{ cfs}}{26{,}550 \text{ sq ft}} = 5.27$ ft per sec. In comparison with the latter figure, the mean of the measured model velocities at this section was 5.33 ft per sec. This comparison reveals that the basic errors in computed velocities lay in computations of discharge distributions. The highest velocities in the navigation channel occurred in the

model in the Chimney Point channel, where a maximum of 6.0 ft per sec was recorded. Computed velocities for this channel were not available.

51. Surface-current directions. Surface currents were observed in the model with a view to locating any troublesome cross currents in the navigation channel, to locating areas suitable for depositing spoil, and to investigating any other items which might be of value in an analysis of the functioning of the Recommended Plan. Plate 22 shows the observed surface-current pattern for the mean flow of 255,000 cfs; this flow pattern is also representative of conditions observed in the model for the minimum and maximum flows. Details of the flow patterns in critical areas are also shown on photographs 9 to 17. It will be noted that flow in the navigation channel was generally parallel to the sailing line. The eddy in the navigation channel opposite the upper edge of Lotus Island (see photograph 14) was somewhat similar to the eddy which exists in the present river channel at Spencer Island Pier. Eddies caused by the side flow into the mouth of the hydraulic channel at the head of Galop Island (see photographs 15 and 16) tended to reduce the efficiency of this channel. The eddy off Cardinal Point (see photograph 14) tended to nullify to some extent the results of the excavation which was made at this point to secure the 2000-ft channel between Cardinal Point and Lalone Island. The wide flare of the left bank of the navigation channel at Lalone Island also caused an eddy (see photograph 14). It will be noted that the area between Galop Island, Lalone Island, and the navigation and hydraulic channels carried very little flow and could well be utilized as spoil area, as could to some extent the area between Galop and Butternut Islands.

Discussion of Results

52. It will be seen from the data presented on plate 19 that the Recommended Plan failed to meet the velocity criteria. As pointed out above, the major reason for the discrepancies between computed and model results lies in the erroneous assumptions upon which computations of discharge distributions were based.

53. Reference to plates 19, 20, and 21 will show that excessive velocities occurred in the cut at Chimney Point for all discharges, and in other portions of the navigation channel for the mean and maximum discharges, while velocities in the hydraulic channel and the Galop Island north channel were somewhat lower than in the navigation channel.

54. An analysis of the results of the above tests of the Recommended Plan indicated the desirability of model tests of the following modifications, in order for the plan to meet the design criteria:

a. Construction of a relief channel between Chimney Island and Drummond Island was needed for the reduction of velocities in the cut between Chimney Island and Chimney Point; there also appeared to be some possibility that this modification might decrease somewhat the discharge in the navigation channel.

b. The efficiency of the hydraulic channel could be improved by eliminating undesirable side-flow conditions in the entrance accomplished by the installation of training dikes and entrance shaping in combination with the lowering of the grade of part or all of the channel entrance from grade 220 to grade 216; the abrupt change of grade at this point caused undesirable flow conditions.

c. There appeared to be a possibility that velocities in the navigation channel could be reduced by enlarging the small channel between Galop and Adams Islands.

d. It appeared that additional excavation at several points might be needed to provide improved flow conditions in the navigation channel. One such point was located in the navigation channel near the lower end of Galop Island, where an abrupt drop in the water surface occurred between gages 4 and 5; it is believed that this drop was caused by the ledge which, in the present river, forms a part of the American Galop Rapids.

e. Full advantage of the relief cut in the Lalone Island south channel was not obtained, as was evidenced by the low velocities in this cut and by the considerable diversion of flow from this channel into the navigation channel through the Lalone and Lotus Island south channel. It appeared desirable that this relief cut be modified either by raising the 214 grade or by extending the cut through the Lotus Island south channel, or by a combination of both.

f. The wide flare on the left side of the navigation channel at Lalone Island caused an eddy. Although this flare was provided for navigation purposes, it is pointed out that it had negligible effect from a hydraulic standpoint.

g. The eddy observed off Cardinal Point indicated that the cut at this point should be realigned to obtain full advantage of the excavation, and also the probability that this excavation could be reduced or entirely eliminated without affecting velocities in this region.

Description of Revised Recommended Plan

55. In accordance with the improvements indicated by the results of the above tests of the Recommended Plan, and in the light of additional information concerning the location of ledge rock, the Revised Recommended Plan was designed by the Office, Chief of Engineers. Plate 23 shows the features of this revised plan, as compared with those of the Recommended Plan; features of the Revised Recommended Plan are described below:

a. Navigation channel. The Chimney Point channel was reduced in width from 1400 ft to 1000 ft, and the alignment was changed. At Butternut Island the excavation to grade 230 was eliminated. Between Butternut Island and Lalone Island the channel was shifted southward, maintaining the width of 600 ft. In the channel from Lalone Island to below Lotus Island no change was made except the removal of the flared entrance. There was no change in the project depth except in the Chimney Point channel, where the project grade was raised from 212 to 214. A cut to grade 225 was provided at the point on the American mainland opposite the southeast tip of Galop Island.

b. Hydraulic channel. The hydraulic channel was extended upstream to include a cut 800 ft wide to grade 225 between Chimney Island and Drummond Island. The alignment of the channel through Galop Island was shifted to take advantage of lower rock contours and deep holes north of the island. The width of the channel was increased from 850 ft to 1000 ft. The flared entrance with excavation to grade 220 was eliminated and the grade was set at 216 to correspond to the grade of the remainder of the channel.

c. Removal of existing structures. Spencer Island Pier, Gut Dam, Locks 27 and 28 and Lock 26 were removed as in the Recommended Plan, and a small area was excavated to grade 225 in the vicinity of Locks 27 and 28.

d. Other features. The relief cut between Lalone Island and the American shore remained unchanged.

Testing of the Revised Recommended Plan

56. The Revised Recommended Plan was tested (following the development of the Final Alternate Plan in the model) for the minimum lake level and maximum discharge. Based on experience gained during the testing of the Alternate Plan, the velocity ranges were relocated.

57. Description of plans tested. The Revised Recommended Plan was tested in a series of steps, which are described briefly below:

Step 1 (see plate 24). This step consisted of tests of the Revised Recommended Plan as designed.

Step 2 (see plate 24). Spoil areas were added.

Step 3 (see plate 25). This step consisted of the addition of a cut to grade 220 in the downstream end of the Lalone and Lotus Island south channel together with a fill along the American mainland opposite Lotus Island.

Step 4 (see plate 26). Cut added in step 3 was raised to grade 230.

Step 5 (see plate 27). Grade of the Drummond Island channel was lowered to 214.

Step 6 (see plate 28). Drummond Island channel was restored

to a grade of 225 and groins were placed along the north edge of the navigation channel from Butternut Island to the vicinity of range 15.

Step 7 (see plate 29). In this test the model was returned to the conditions of step 2 and a dam was placed in the channel between Lalone Island and the American shore.

Steps 8A and 8B (see plate 30). In step 8A the width of the navigation channel was increased from range 16 to 22 by shifting the south limit of the channel. For step 8B the dam in the Lalone and Lotus Island south channel was removed.

Step 8C (see plate 31). Lalone Island south channel was restored to natural conditions.

Step 8D and 8E (see plate 32). In step 8D the navigation channel was increased in width to 800 ft between ranges 16 and 22 by shifting the north limit of the channel. For step 8E the Lalone Island south channel was closed by a dam.

Step 8F (see plate 33). Spoil area at Dead Man's Rapids was removed.

Step 9 (see plate 34). Same as step 8D except that a training dike was constructed along the south side of the navigation channel, beginning at the edge of deep water above Butternut Island and extending downstream to the point of the American shore opposite Galop Island. On the north of the navigation channel a training dike was added, extending along the edge of the channel from Butternut Island to the vicinity of range 13.

Step 10 (see plate 35). The training walls of step 9 were removed and a 2100-ft training dike was installed along the south edge of

the navigation channel extending upstream from Lalone Island.

Step 11 (see plate 36). Grade of the hydraulic channel was lowered from 216 to 210 between the entrance at Tick Island and the lower end of the cut through Galop Island.

Step 12 (see plate 37). Excavation to grade 210 was extended downstream to Dixon Island.

Step 13 (see plate 38). Grade of the Drummond Island channel was lowered to elevation 210.

Results of Tests of Revised Recommended Plan

58. Step 1 (see plates 39 and 42). Velocities measured in the Chimney Point channel were lower than those produced by the Recommended Plan and satisfied the velocity criteria. However, velocities exceeding 5.25 ft per sec were measured between ranges 14 and 22. The maximum velocity recorded was 6.12 ft per sec on range 18. Velocities in the hydraulic channel were increased somewhat over those of the Recommended Plan.

59. Step 2 (see plates 40 and 42). Addition of the spoil areas produced a beneficial effect in that maximum velocities were reduced generally except on a few ranges.

60. Step 3 (see plate 43). The additional area provided and streamlining of the lower reach of the Lalone and Lotus Island south channel served to increase the velocities in the navigation channel between ranges 14 and 20 and reduced those between ranges 22 and 24.

61. Step 4 (see plate 43). Raising the bottom grade of the cut in the lower portion of the Lalone and Lotus Island south channel reduced

velocities in the navigation channel to a small extent.

62. Step 5 (see plate 44). Increasing the depth of the Drummond Island channel caused a reduction in the velocities in the Chimney Point channel but served to increase them slightly in the navigation channel below Galop Island.

63. Step 6 (see plate 45). The groins in step 6 produced a substantial decrease in the velocities between ranges 17 and 22 and an average increase of 1 ft per sec between ranges 8 and 15 opposite the groins.

64. Step 7 (see plate 46). In step 7 it was found that stopping the flow through Lalone and Lotus Island south channel, designed to reduce a side-wise draw, increased velocities on range 22 to a maximum of 7.3 ft per sec. A slight reduction in velocities was obtained between ranges 15 and 21.

65. Steps 8A and 8B (see plates 47 and 48). In step 8A the widening of the navigation channel caused an increase in the velocities between ranges 15 and 20, and a large reduction at range 22 at the point of maximum increase in area. Removal of the Lalone Island dam (step 8B) produced a decided decrease in the velocities between ranges 20 and 23 but the velocities were increased between ranges 15 and 19.

66. Step 8C (see plates 49 and 50). Model tests of step 8C with the Lalone and Lotus Island south channel restored to natural conditions produced velocities which checked so closely with those in step 8B that it was evident that the excavation in the Lalone Island south channel was ineffective.

67. Step 8D (see plates 51 and 53). The additional widening of

the navigation channel in step 8D, as compared with 8B, resulted in increases and decreases in velocities throughout the channel; however, more nearly uniform maximum velocities were obtained throughout the channel than in the plans heretofore tested.

68. Step 8E (see plates 49, 52, 53, and 54). The damming of Lalone and Lotus Island south channel in step 8E again produced high velocities in the vicinity of range 22. The lower velocities on ranges 17 and 18 may be attributed to a pooling effect caused by backwater from the dam.

69. Step 8F (see plate 54). Removing the spoil area in Dead Man's Rapids showed little benefit from the velocity-reduction standpoint. A large, slow eddy developed which restricted the flow from the navigation channel through this opening into the hydraulic channel.

70. Steps 8A through 8F. During the testing of steps 8A through 8F, studies were conducted of current directions in the vicinity of ranges 19 through 22. Results of these studies are shown on plates 59 to 63. The effect of opening the Lalone and Lotus Island south channel can be determined by comparing the results of step 8A (plate 59) with those of step 8C (plate 60), and the results of step 8D (plate 61) with those of step 8E (plate 62). These tests indicated that the angle of the sidewise draw would be increased about 5 degrees from ranges 19 through 21 by the proposed cut, and that the maximum velocities would be increased about 0.3 ft per sec at ranges 19 and 20 and reduced about 0.5 ft per sec from ranges 20-A through 22. A comparison of step 8E (plate 62) with step 8F (plate 63) shows the negligible effect of opening Dead Man's Rapids (by removing the spoil area) on current directions and velocities.

71. Step 9 (see plate 53). By comparing the results of step 9 and step 8D it will be noted that the training dikes effected a small reduction in velocities at ranges 18 and 19, but that velocities in the remainder of the channel were increased. A comparison of the results of tests of step 9 and step 2 will show that the combined effects of the training dikes, the widening of the navigation channel, and the removal of the cut in Lalone and Lotus Island south channel, were to increase the velocities in the vicinity of the training dikes while those in the widened section were reduced slightly, except at ranges 22 and 23 where an increase occurred. Step 9, although an improvement over step 7, revealed, from the velocity standpoint, the same results, velocities being increased throughout the walled areas due to the decreased width of the channel.

72. Steps 10 to 12 (see plates 55 and 56). The training dike in step 10 caused reduction of velocities on ranges 16 through 18, no change on ranges 19 and 20, and an increase on ranges 21, 22, and 23. Examination of plate 56 will reveal that lowering the grade in the hydraulic channel between Tick and Dixon Islands in steps 10, 11, and 12 had very little effect on the velocities in the navigation channel, although the velocities for step 12 were slightly lower.

73. Step 13 (see plates 41, 57, and 58). Step 13 was the culmination of the model development of revisions to the Recommended Plan. The velocities obtained were generally comparable with those of the tests of the Final Alternate Plan, as described in the next part of this report.

Discussion

74. As stated above, the velocities finally obtained in the Revised Recommended Plan were generally comparable with those obtained in the Final Alternate Plan.

PART VII: THE ALTERNATE PLAN

Description of the Original Alternate Plan

75. The Alternate Plan for the improvement of the Galop Rapids Section of the St. Lawrence River was based upon the concept of reducing the water-surface slope by creating a single navigable channel, and reducing the velocities through this channel by modification of existing channels and structures so as to meet certain prescribed velocity criteria. Features of this plan are shown on plate 64 and are described below:

a. Navigation channel. The navigation channel was located along a relatively straight course from Chimney Point to below Lotus Island by cutting through Galop Island. The channel was 1600-ft wide from Chimney Point to below Galop Island. From this latter point a flare provided an 1800-ft width for velocity reduction. Excavation of the navigation channel was to grade 214, except that all rock was excavated to grade 211.* Dikes were provided along both sides of the channel above and below Galop Island to prevent cross currents and increase the friction of the channel, thereby decreasing the fall in the water surface per unit distance. (The plan layout of the excavation involved and the

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* The design criteria followed by the Massena Office required that rock in navigation channels be excavated 3 ft below project grade. For simplification of model construction the center 800 ft of the channel was built to grade 211 in the Galop Island cut between Tick Island and Dixon Island. It was assumed that this procedure would produce hydraulic effects very similar to those which would obtain had the various areas where rock occurs been constructed to this grade.

location of dikes are shown on plate 64).

b. Relief cut in Lalone-Lotus Island south channel. The Lalone-Lotus Island south channel was enlarged by a cut 600 ft wide to grade 214, in order to utilize more fully the capacity of the Galop Island south channel. (The plan layout of the excavation involved is shown on plate 64.)

c. Treatment of existing structures. Spencer Island Pier was removed for the purpose of improving flow conditions in the navigation channel opposite Chimney Point.

Model Tests of the Alternate Plan

Scope of tests

76. The initial model tests of the Alternate Plan were made for the purpose of providing a check on the hydraulic computations of this plan and determining the effects of modifying the plan by the removal of dikes.

Surface roughness of excavated channels

77. Since a roughness value (Manning's "n") of 0.020 was used in the design computations as the coefficient of roughness of excavated areas, especial efforts were made to obtain a corresponding value in the model. To determine the roughness to be used in the excavated channels in the model, a test section was selected which began just above Galop Island and ended near the lower end of Dike 4. After placing stucco roughness on the excavated areas, flow in the model was confined to the test section by placing dams across the north and south Galop Island

channels. The tailwater elevation was regulated to obtain a water-surface profile somewhat comparable with the water surface to be obtained with the completed project. Water-surface elevations were obtained at several points and the cross-sectional area and hydraulic radius determined for each of the ranges located at these points. Water-surface profiles in the test section were obtained for discharges corresponding to 275,000, 240,000 and 200,000 cfs. Roughness values of 0.019, 0.020, and 0.021 were obtained for these discharges, respectively. The roughness of those excavated sections lying outside of the test section was adjusted to correspond to the roughness obtained in the test section. The roughness of all natural channel surfaces was identical with that found necessary in the verification of the model.

Testing procedure

78. Method of operation. The original Alternate Plan was tested for maximum, mean, and minimum discharges. The governing elevation at Chimney Point for each discharge was the same as that used for the Recommended Plan (see paragraph 46). The tailwater elevation below Lotus Island (gage 6) was manipulated in each case until the correct elevation was obtained at Chimney Point. The data obtained during the testing of the Alternate Plan consisted of water-surface profiles, discharge distributions, velocities, and surface-flow patterns. Surface current directions were obtained photographically.

Results of model tests (compared with computations*)

79. Water-surface profiles. Plate 65 shows the new center-line

* The computed results mentioned herein were obtained from Appendix A-2, General Data, St. Lawrence River Project, Final Report of 1942.

stationing which was developed by the Experiment Station for studies of the Alternate Plan. Water-surfaces profiles for the maximum, mean, and minimum discharges are shown on plate 66. A comparison of model and computed stages at Chimney Point and below Lotus Island, for a discharge of 310,000 cfs, is furnished by the following tabulation:

	Computed Elevation		Model Elevation
	Massena	O.C.E.	
Chimney Point	244.27	244.27	244.24
Below Lotus Island	243.27	243.05	242.88
Drop in feet	1.00	1.22	1.36

The computed results obtained by the Massena Office were based on "n" values and energy losses obtained from a study of the Toussaints Island reach. These values were somewhat lower than the "n" values and losses which were used by the Office, Chief of Engineers. In view of the facts that these latter losses were the same as those used by the Office, Chief of Engineers, in their computations for the Recommended Plan, and that the computations of the Massena District for the Alternate Plan were based upon a plan slightly different from the one finally adopted, it was recommended in Appendix A-2 of the St. Lawrence River Final Report of 1942 that the computations of the Office, Chief of Engineers, be accepted in preference to those computations made by the Massena Office.

80. It will be noted that the drop between Chimney Point and Lotus Island, as shown by the model, was slightly greater than the drop shown by the computations of the Office, Chief of Engineers. As has been pointed out in the report on the Recommended Plan, it is believed that the assumed roughness value of 0.025 used in O.C.E. computations was too low, which would account in part for the slight variation of the computed

results from the model results.

81. Discharge distribution. A comparison between model and computed discharge distributions for a total river flow of 310,000 cfs is shown by the following tabulation:

Channel	Computed Discharge		Model Discharge	
	cfs	Percent of Total Flow	cfs	Percent of Total Flow
Galop Island south	58,000	18.7	62,500	20.1
Navigation	230,000	74.2	231,000	74.6
Galop Island north	22,000	7.1	16,500	5.3
Total	310,000	100.0	310,000	100.0

The discharge distribution for the minimum and mean discharges as well as the maximum discharge may be seen on plate 67. It will be noted that a straight-line variation of percentile discharge with total river flow is indicated. (As an indication of the accuracy of the model discharge interceptors, the sum of the discharges in the Galop Island south, navigation, and Galop Island north channels checked within one percent the total flow in the river.)

82. Velocities. Plates 68, 69, and 70 show velocities measured in the model tests of the Alternate Plan. According to computations, the maximum velocity in the navigation channel would be 4.75 ft per sec in the cut opposite Dixon Island; the maximum average velocity in the model (obtained by averaging the velocities at five points in each range measured) was 5.28 ft per sec at the lower end of Galop Island. For the Galop Island cut, the computations showed a velocity of 4.69 ft per sec; in the model an average of the average of velocities for the several ranges through this cut was 4.85 ft per sec.

83. Surface-current directions. Surface currents were observed in

the model in order to locate any troublesome cross currents in the navigation channel, to determine areas suitable for spoil disposal, and to investigate any other points which might be of value in an analysis of the functioning of the Alternate Plan. Plate 71 shows the surface-current pattern for the mean flow of 255,000 cfs (this flow pattern is also representative of conditions observed in the model for the minimum and maximum flows). Details of the flow pattern are also shown on photographs 18 to 24. Flow in the navigation channel was found to be generally parallel to the alignment of the channel.

Discussion of results

84. It was realized at the time the Alternate Plan was designed that it would not meet fully the velocity criteria. This was confirmed by the functioning of the plan in the model. It was apparent, however, that the Galop Island north channel could be made to carry more water by removing certain dikes and thus reducing the velocities in the navigation channel. There was a differential of 0.5 ft between the water-surface elevations in the navigation channel and the Galop Island north channel along Dikes 6A, 6B, and 6C. The currents in the Galop Island south channel were so sluggish as almost to form a pool along Dikes 5 and 5B. The water surface in the Galop Island south channel above Butternut Island was approximately 0.6 ft above the water surface in the navigation channel, indicating a tendency for the cross currents which exist in the present river above Butternut and Tick Islands.

Study of Effects of Dikes

Testing procedure

85. The following dikes and structures were removed progressively (see plate 64): all of Dike 6; Gut dam; Locks 27 and 28; Dike 5B; Dike 5A; Dike 4 from its lower end to Galop Island; the remainder of Dike 4 along the north side of Galop Island; and Dike 5C. Velocity measurements at the maximum discharge and minimum lake level were taken at the following points in the navigation channel: three ranges in the vicinity of Chimney Island and Drummond Island; three ranges in the vicinity of the upper end of Galop Island; three ranges in the vicinity of the lower end of Galop Island; and two ranges opposite Cardinal Point. To determine the flow in the other channels, velocities were measured at the following points: three points between Chimney Point and Chimney Island; one point in the Galop Island south channel opposite the lower end of Galop Island; and two points in the Galop Island north channel below Adams Island. The effects of the removal of these structures are discussed briefly in the following paragraphs, the percentile velocity comparisons given being approximate.

Results of tests

86. Removal of Dikes 6A, 6B, and 6C. In an attempt to increase the discharge through the Galop Island north channel, all three sections of Dike 6 were removed. The desired effect was obtained, as indicated by the tripling of the velocities in this channel. In the navigation channel through Galop Island, velocities were decreased between 5 and 10 percent. Velocities opposite Cardinal Point, as well as those in the Galop

Island south channel, remained substantially the same. However, the velocities in the Drummond Island channel were increased 12 to 15 percent.

87. Removal of Gut Dam and Locks 27 and 28. Removal of these structures (following the removal of Dikes 6A, 6B, and 6C) increased the velocities between Chimney Island and Drummond Island 15 to 20 percent, and decreased only slightly the velocities in the navigation channel at Galop Island. No change was noted in the velocities in the south channel.

88. Removal of Dike 5B. Removal of this dike caused a decided flow from the Galop Island south channel into the navigation channel at Butternut Island. The division of flow at Chimney Island shifted northward to the channel line of the navigation channel; the effect of removal of this dike on the division of flow at this point may be seen by comparing photographs 18 and 25. The velocities between Chimney Island and Chimney Point were almost doubled. No change could be detected in the velocities in the Galop Island north channel. The velocities in the Galop Island south channel below Butternut Island were decreased, while very little difference could be noted in the navigation channel through Galop Island. Velocities between Chimney Island and Drummond Island were decreased 15 to 20 percent.

89. Removal of Dike 5A. Removal of this dike had no noticeable effect on the velocities at any point. However, the slow, variable eddy below Chimney Island which was present with the river in natural conditions reappeared. This eddy extended over the south channel line of the navigation channel. Photograph 25 depicts this condition.

90. Removal of Dike 4. Removal of this dike caused only minor reductions in the velocities through the lower Galop Island cut. The

points of Galop Island remaining after the excavation of the navigation channel tended to prevent mingling of the currents from the navigation channel and the Galop Island north channel, the only exception being a slight diversion of flow which occurred between Galop Island and the first Galop Island point (see photograph 28).

91. Removal of Dike 5C. Removal of this dike caused a diversion of flow from the Galop Island south channel into the navigation channel between Butternut and Galop Islands. This caused an unsatisfactory entrance condition at the head of Galop Island and raised the velocities at this point approximately 5 percent.

92. Removal of Dike 2. In view of the fact that the area between the Galop Island south channel and the navigation channel and between Galop Island and Lotus Island would be utilized as a spoil area, no studies were made to determine the effect of removing Dikes 1, 2, and 3. For a demonstration, however, Dike 2 across Dead Man's Rapids was removed, with the result that an unsatisfactory cross current was set up into the navigation channel which probably would tend to increase velocities opposite Cardinal Point.

93. Discussion. As has been pointed out above, the major improvement to the Alternate Plan was accomplished by the removal of Dikes 5B and 6, Gut Dam, and Locks 27 and 28. Insofar as velocities were concerned, Dikes 5A and 4 effected no apparent improvement or detriment to the project and for that reason may be considered as unnecessary. Dike 5C improved flow conditions considerably at the head of Galop Island. Removal of the dikes decreased the head loss between Chimney Point and below Lotus Island as pointed out in paragraph 95 below.

Improved Alternate Plan

Description of Improved Alternate Plan

94. The results of the above tests of the Alternate Plan indicated that lower velocities would be obtained in the navigation channel by the removal of certain dikes and structures. Accordingly, model tests were made of the "Improved Alternate Plan", which was identical with the original Alternate Plan except for removal of the following structures: Dikes 6A, 6B, and 6C; Gut Dam; Locks 27 and 28; and Dikes 4, 5A and 5B. The Improved Alternate Plan is shown on plate 72. The data obtained from these tests were used as a basis of comparison for subsequent tests of plans embodying alterations to the width, depth, or alignment of the Alternate Plan.

Results of tests of Improved Alternate Plan

95. Water-surface profiles. Using the same center-line stationing as shown on plate 65, water-surface profiles for the maximum, mean, and minimum discharges were measured and are shown on plate 73. For the maximum discharge the drop between Chimney Point and below Lotus Island (gage 6) was 1.04 ft as compared with the 1.36 ft obtained with the dikes in place.

96. Discharge distribution. A comparison of discharge distributions for a total river discharge of 310,000 cfs for the original Alternate Plan and the Improved Alternate Plan is shown by the following tabulation:

Channel	Original Alternate Plan: Discharge in cfs	Original Alternate Plan: Percent of Total River Flow	Improved Alternate Plan: Discharge in cfs	Improved Alternate Plan: Percent of Total River Flow
Galop Island south	62,500	20.1	47,200	15.2
Navigation	231,000	74.6	217,000	70.0
Galop Island north	16,500	5.3	45,800	14.8
Total	310,000	100.0	310,000	100.0

The discharge distributions for the mean and minimum discharge, as well as the maximum discharge, are shown on plate 67, which also shows the discharge distribution for the original Alternate Plan and permits a direct comparison of the effects of the removal of the dikes. The discharge through Galop Island south channel and the navigation channel was decreased while flow through the Galop Island north channel was increased considerably. From the base tests, it will be remembered that the flows in the Galop Island north and south channels were very nearly equal; it is interesting to note that this condition of near equality of discharge in these channels was again attained with the Improved Alternate Plan.

97. Velocities. Plates 74, 75, and 76 show the velocities observed in tests of the Improved Alternate Plan. For the maximum discharge, an average of the spot velocities for each range showed that the maximum average velocity was 4.20 ft per sec at Cardinal Point. A maximum spot velocity of 5.16 ft per sec was measured at this point. All other average velocities were under 4.0 ft per sec.

98. Surface-current directions. Surface-current directions are shown on plate 77 and photographs 25 to 33. Above Butternut Island the flow from the Galop Island south channel into the navigation channel and

from the navigation channel into the Galop Island north channel occurred without a direct cross current. This was determined by a careful study of both surface and subsurface currents.

Development of the Final Alternate Plan

General procedure

99. Model tests of the Improved Alternate Plan produced velocities considerably lower than the maximum allowable under the velocity criteria outlined above. Furthermore, a detailed analysis of subsurface exploration data by Mr. Vincent R. Stirling, Engineer, (employed by the New York District Engineer as resident consultant on the model study) indicated that the quantity of rock excavation could be reduced by certain channel realignments. With these two points in mind, relocations and reductions in width of the navigation channel were made with a view to reducing rock excavation to a minimum.

Testing program

100. The development of the Final Alternate Plan was the culmination of a lengthy series of studies of progressive design modifications which were developed as the work progressed. The paragraphs below present descriptions of the various modifications tested. Except where otherwise noted, these modifications were added progressively to the Improved Alternate Plan.

101. Step 1 (see plate 78). This step was concerned with relatively minor changes in the vicinity of Lock 26, where the canal banks were streamlined and a small amount of excavation to grade 220 was added in

an effort to improve flow conditions.

102. Step 2 (see plate 79). The channel in the vicinities of Chimney Island and Tick Island was narrowed from 1600 ft to 1400 ft, the reduction being effected by shifting the south limit of the channel. Through the Galop Island cut, the 1600-ft channel was narrowed to 1450 ft by shifting the south limit of the channel.

103. Step 3 (see plate 80). Galop Island cut was narrowed from 1450 to 1300 ft from the south side.

104. Step 4 (see plate 81). The points of Galop Island remaining after the excavation of the navigation channel, together with additional areas extending to the 214 contour of the existing river bed, were excavated to grade 214.

105. Step 4A and 4B (see plate 81). In step 4A, training dikes of various lengths and alignments were tried at the head of Galop Island along the north edge of the channel; no results of these dikes are reported. For step 4B, a 1600-ft training dike was placed in this location, 1000 ft of this dike following the north edge of the channel and the outer 600 ft turning about 15 degrees northward.

106. Step 4C. A slight curve easement was provided on the south edge of the channel from ranges 19 to 21.5, and all dikes between Butternut and Lotus Islands were moved to within 30 ft of the cut.

107. Steps 5 and 5A2 (see plate 82). Step 5 was a radical change in alignment to take advantage of lower ground and rock. Utilization was made of the hydraulic principle of providing equivalent hydraulic cross-sectional area with increased depth and decreased width. Alignment of the channel through Galop Island was changed to decrease the quantity of

excavation in this and adjacent reaches. The north limit of the channel of the Alternate Plan in the vicinity of ranges 6, 7, and 8 was extended to intersect the shore line of Galop Island at the downstream end of the Galop Island south channel, the point thus established providing a point on the north limit of the realigned channel. The western terminus of the north limit of the relocated channel (between ranges 4 and 5) was established by moving the point of intersection with the Alternate Plan in a southerly direction by 200 ft. The south limit of the relocated channel was made parallel to and 1400 ft from the north limit. For the following descriptions of the navigation channel through that portion of Galop Island indented by the coves, the north limit of the channel of the Alternate Plan is used as a line of reference; this line is significant because it marks the line of the proposed construction cofferdam. In this reach, the south limit of the relocated channel was established parallel to and 1000 ft south of the above reference line, and was extended upstream to an intersection with the south limit of the channel above. Thus, a channel somewhat wider than 1400 ft was provided through the lower portion of Galop Island. For a distance of approximately 4500 ft between ranges 13 and 17, the channel grade was lowered to grade 200, each end of this deepened reach being provided with a grade transition with a 20-to-1 slope. The south limit of the channel of the Alternate Plan in the vicinity of ranges 18-20 was extended upstream to an intersection with the south limit of the channel through Galop Island to establish a point on the new channel. In addition to the above-described features of step 5, step 5A2 is also shown on plate 82. This latter step consisted of the addition of a training dike in the navigation channel at

the head of Galop Island to eliminate side flow and eddy action in the mouth of this channel. This dike was retained in the subsequent modifications.

108. Step 5B (see plate 83). Width of the 4500-ft deepened area (to grade 200) was reduced to 750 ft, measured from the reference line described in the preceding paragraph.

109. Step 5C (see plate 84). The deepened area (to grade 200) was restored to project grade and the 1000-ft width again installed.

110. Step 5D (see plate 85). The flared portion of the navigation channel in the vicinity of ranges 12 and 13 was narrowed to 1400 ft by realigning the north limit of the channel.

111. Step 5E (see plate 86). The model was returned to the step 5C conditions except that the channel width from ranges 14 to 17 was reduced to 750 ft.

112. Step 5 E' (see plate 87). Spoil areas were added.

113. Step 5F (see plate 88). The navigation channel between Chimney Island and Drummond Island was reduced to a 1300-ft width, the narrowing being effected from the north limit. In addition, a curve easement was provided in the south limit of the channel between Dixon Island and range 21.

114. Step 5G (see plate 89). The point on the American mainland opposite the upper end of Galop Island was removed to elevation 230.

115. Step 6 (see plate 90). The south limit of the channel in the Chimney Island-Drummond Island reach (ranges 1-3) was shifted to the location used in the Alternate Plan, and the width of the channel was reduced to 1100 ft. Between ranges 5-8, the north limit of the channel was the

214 contour. Through ranges 9-13, the 1400-ft channel utilized previously was installed. In the reach between ranges 14-17, the channel was 655 ft wide (measured from the reference line) and was excavated to elevation 206. The easement utilized in step 5F, between Dixon Island and range 21, was used in this step with a small amount of additional excavation in the vicinity of range 17. A submerged spoil dump to elevation 225 was added at Frazier Shoal.

116. Step 6A (see plate 91). The channel between ranges 14 and 17 was restored to project grade over a 750-ft width, with necessary additional excavation to grade 214 to provide a width of 1950 ft.

117. Step 6B (see plate 92). The north limit of the channel was shifted southward to the 214 contour between ranges 14 and 17.

118. Steps 6C to 6K. Steps 6C to 6K were a series of tests devoted to checking the results of previous steps, in order to eliminate the possibility of any errors in velocity measurements. Step 6K, hereinafter referred to as the "Final Alternate Plan", is discussed below.

Final Alternate Plan

Description

119. The development of the Final Alternate Plan (shown on plate 93) was the culmination of the modifications to the original Alternate Plan. For this plan, the navigation channel at Drummond Island was 1100 ft wide. The south limit of the channel was the same as that in the Alternate Plan. Between ranges 6 and 9, the north 214 contour line was the effective north limit of the channel. This provided a channel varying in width from 900 ft to 1400 ft with good navigation alignment. At

the head of Galop Island, a training dike 2200 ft long with a slight flare in the last 600 ft was installed along the north limit of the channel. Between ranges 9 and 13, a channel 1400 ft wide was provided. Between ranges 14 and 17, the channel was excavated to grade 214 (except that rock was cut to 211) to the 214 contour. An easement was provided along the south limit of the channel between ranges 17 and 21 with an additional small amount of easement excavation at range 17. In the vicinity of Lock 26, excavation to grade 220 was provided. The point on the American mainland opposite the upper end of Galop Island was removed. The Lalone-Lotus Island south channel was excavated to grade 214 over a 600-ft width. River areas for the disposal of spoil were provided.

Testing procedure

120. Data obtained. In the steps leading up to the Final Alternate Plan, only velocities for the maximum discharge at the minimum lake level, the most severe combination of conditions to be imposed on the completed project, were measured. However, for the tests of the Final Alternate Plan, velocities, water-surface profiles, surface flow patterns, and photographs were obtained over a wide range of discharges and lake levels. The variations in lake levels with discharge resulted from the application of Regulation Method No. 5 (see paragraph 9) to the hydrological records of the St. Lawrence River. From a plot of stage against discharge (monthly averages) for the period of record, there was developed an envelope curve which depicted the maximum and minimum lake levels to be obtained under any discharge (see plate 114). From this envelope curve the following control elevations at Chimney Point were obtained:

Discharge in cfs	Lake Ontario Elevation	Chimney Point Elevation	Condition
310,000	246.5	244.27	Max. Discharge Min. Lake level
310,000	247.8*	246.00	" " Mean " "
310,000	249.1	247.50	" " Max. " "
255,000	246.0	244.40	Mean " Min. " "
255,000	247.4	246.35	" " Max. " "
220,000	245.15	244.00	Max. winter disc. Min. " "
220,000	246.75	245.76	" " " Max. " "
180,000	244.0	242.93	Min. discharge

* Mean of maximum and minimum lake level.

Results of tests

121. Method of analysis. A sufficient number of velocities were obtained during the testing of each step to determine the effects of the change in design. A graph was prepared for each step showing the maximum velocity for each range. The velocities in each range were averaged and this value was also plotted. The theoretical maximum velocity (115 percent of the average velocity) was also plotted. Points where the actual maximum velocities were higher than the theoretical values indicated the need of modifications to secure a redistribution of flow with a view to reducing the actual maximum velocities. For demonstration purposes, the results obtained for step 2 were plotted on plate 94. It will be noted that from range 12 through range 21 (in an area of rock excavation) the theoretical maximum velocity was 5 to 10 percent lower than the actual maximum, indicating that all parts of the hydraulic cross-sectional area were not utilized to the fullest extent. These facts are borne out by another graph used in the analysis of data--the transverse velocity plots shown on plate 95.

122. The studies which were made in the development of the Final Alternate Plan resolve into three separate phases: (a) Phase 1,

concerned with the tests between the Improved Alternate Plan and step 5; (b) Phase 2, involving experimentation with modifications of steps 5 and 6; and (c) Phase 3, concerned with the correlation of these studies and the ultimate development of the Final Alternate Plan. These three phases are discussed in the paragraphs below.

Phase 1 (Steps 1 to 5)

123. The excavation at Cardinal Point in step 1 improved the appearance of the flow pattern in the immediate vicinity of the point, but had no appreciable effect on the maximum velocity. Step 2 compared with the Improved Alternate (see plate 96) shows the expected increase in velocity from range 1 through 17. For step 3, which contained an additional 150 ft narrowing between ranges 13 and 17, it is interesting to note the increase in velocities extended from range 17 to range 11 (see plate 96). This phenomenon was noted throughout the course of the study; viz, changes made in the vicinity of the lower Galop channel had a marked effect on velocities in the upper Galop channel. In step 4, the removal of the remainder of the points of Galop Island provided additional cross-sectional area between ranges 14 and 17, with a resultant reduction of velocities between ranges 16 and 20 (see plate 96). The major benefit derived from the improvement was the elimination of flow disturbances caused by the points. As testing proceeded, it became apparent that a training dike would be necessary to streamline the flow entering the navigation channel at the upper end of Galop Island. Varying lengths of dikes at this location were tested. The most effective length of dike (step 4B) was found to be approximately 1950 ft,

measured from the shore line of Galop Island. The effect of this dike (see plate 97) was to decrease the magnitude of the maximum velocity and shift its location upstream. The results of the minor curve easement of step 4C are shown on plate 97.

124. Plate 98 shows a comparison between the maximum velocities for step 5 and the Improved Alternate Plan. Step 5 was designed to provide a hydraulic cross-sectional area equal to that provided in the Improved Alternate Plan between ranges 14 and 17, and it is interesting to note that the velocities in this reach for the two plans were almost identical, while the velocities upstream from range 14 were higher for step 5F than for the Improved Alternate Plan.

Phase 2 (Steps 5 and 6 modifications)

125. The first modification to step 5 was made in a series of studies devoted to the development of the most efficient length for a training dike at the head of Galop Island. Step 5A2 was a test of a 2100-ft dike, the results of which are shown on plate 99. The effect of this dike was to lower the maximum velocity and to shift its location upstream. In all subsequent tests in the step-5 series, this dike was utilized. Plate 100 presents a comparison of the results of steps 5A2, 5B, 5C, and 5E, which involved different widths and grades in the reach between ranges 14 and 17. An analysis of these results revealed that the deeper channel was more efficient than the channel of equal section excavated to project grade. This may be observed by comparing step 5B and 5C. The hydraulic cross-sectional area provided between ranges 14 and 17 was nearly identical in both cases, yet the maximum velocity for step 5B (the

deeper channel) was lower than the maximum velocity for step 5C.

126. Step 5D was a study of the effect of a reduction in channel width accomplished by shifting the north limit of the channel in the vicinity of ranges 12 and 13. Although this wedge had little effect on the velocities at ranges 14 to 17 (see plate 101), it did improve the flow pattern at the junction of the flow from the navigation channel below Galop Island and the Galop Island north channel.

127. Step 5E' was a study of the spoil areas, the locations of which were based upon the utilization of areas which were hydraulically ineffective. The spoil areas had little effect on the velocities in the navigation channel (see plate 102). Tests were also conducted of the effects of a dumping area in the deep water in the vicinity of Frazier Shoal opposite Lotus Island. Although this spoil area had little effect on the velocities at ranges 21, 22, 23, and 24, its possible effects at and below Sparrowhawk Point could not be determined in the Galop Rapids Model. The results of steps 5F and 5G are presented on plate 103 (a discussion of these results is presented in a later part of this report). Step 6 was developed from an analysis of the results of steps 5A2 through 5E. This analysis did not take into consideration the provision of suitable transitions in grade, as is evidenced by the extremely high velocities on ranges 16-18 for step 6 (see plate 104). Because of the impracticability of providing a suitable transition, further step-5 modifications were abandoned. In step 6A, the additional excavation lowered velocities on ranges 14-16; however, the velocities above and below these ranges remained higher than the allowable maximum.

128. Step 6B was very nearly identical with step 5F with the

exception that the navigation channel at Drummond Island was reduced to a width of 1100 ft in step 6B, and a general agreement in the velocities for these two conditions was expected below range 8. However, step 6B produced substantially higher velocities from ranges 17 to 21, although the expected agreement with step 5F was obtained on ranges 6 through 8. At first, it was believed that the narrowing of the navigation channel in step 6B had affected velocities at Cardinal Point. Several series of tests were conducted before the error of this conclusion was established. This investigation finally brought out the fact that the technique used in making velocity measurements had not been properly perfected. Some error in velocity measurements is therefore possible in all of the studies through step 5G, due to the fact that the floats used to measure velocities were placed in the water too close to the measuring range, so that in some cases they failed to reflect the full velocity of the water. This technique was corrected for step 6 and all subsequent steps. Considerable time and effort were devoted to attempts to check previously-obtained model velocities, with a view to picking out any erroneous measurements; however, excellent checks (under the corrected technique) were obtained of velocities on all points except ranges 17 through 21. No definite correction factor could be worked out, so the velocities presented throughout this report are as actually measured in the model. The errors on ranges 17 through 21 (prior to step 6) are possibly attributable to the accelerating velocity in this reach which the floats did not reflect properly on very short runs. The data for step 6 and subsequent tests, however, are believed to be a true representation of velocity conditions over all ranges. Velocity measurements for the Revised

Recommended Plan step 13 and the Final Alternate Plan employed the improved technique.

Phase 3 (Final Alternate Plan)

129. In this phase, a study was made of the performance of all modifications of the Alternate Plan and the Final Alternate Plan was designed on that basis. A description of the physical features of this latter plan is presented in paragraph 119 above. Plate 105 shows the maximum velocities for this plan. The average velocities are also shown on this plate, each plotted point representing the average of the five velocities measured across that particular range. Also plotted on this plate is a graph representing 115 percent of the average-velocity plot, this value being assumed as the theoretical maximum velocity to be encountered. A comparison of this plate with plate 94 will show that much was accomplished toward improving the flow distribution and obtaining utilization of the full hydraulic cross sections of the channel, as indicated by the close relation between the theoretical maximum and the actual maximum velocities.

Tests at other lake levels and discharges

130. The Final Alternate Plan was next tested for the remainder of the discharges and stages listed in paragraph 120. The results of these tests are presented in the form of transverse velocity curves on plates 106, 107, and 108. It will be noted that symmetrical patterns across the sections were obtained for all stages and discharges.

131. Velocities in the secondary channels. Velocities in the secondary channels were obtained for the minimum lake level for the

discharges tested. These data, together with the velocities in the navigation channel, are shown on plates 109 to 112.

132. Water-surface profiles. During these tests, the Department of Transport gages which were not within spoil areas were read, and from these data the water-surface profiles shown on plate 113 were developed. As expected, the total drop between Chimney Point and Lotus Island decreased with a decrease in discharge and an increase in the stage of the lake. At the maximum discharge at minimum lake stage, the total drop was 1.20 ft as compared with the 1.04-ft drop obtained with the Improved Alternate Plan.

133. Surface current directions. Surface current directions for the Final Alternate Plan at the maximum discharge and minimum lake level are shown on photographs 34 to 43. Attention is invited to photograph 36 which shows side flow from the Galop Island south channel into the navigation channel in the vicinity of Butternut Island. This flow continued down the navigation channel with no crossover into the Galop Island north channel.

134. Maximum spot velocity. Examination of plates 106, 107, and 108 will show that the maximum spot velocity for the Final Alternate Plan occurred at range 17, point 2. To aid in the analysis of operations over a wide range of conditions, plate 114 was prepared. This curve depicts the maximum velocities which can be expected at any discharge and lake level under Regulation Method No. 5. In addition the total drop between Lotus Island and Chimney Point may be determined. It is pointed out that although velocities of over 5.25 ft per sec are to be expected, a combination of lake level and discharge which would produce this condition would occur only 3 months in 640 months, or less than one percent of the time.

PART VIII: PROTOTYPE CONSTRUCTION PROGRAM

Introduction

135. The discussions presented herein were taken largely from a report prepared by the District Engineer on the tentative construction program.

136. Because of the rigorous winters, with resultant ice cover on the river, construction on the St. Lawrence Project would be largely confined to a working season beginning in April and extending to November. Completion of the project would require several seasons of construction. However, in this discussion, comments are confined to the Galop Rapids section of the St. Lawrence River.

137. A fundamental consideration throughout the construction period is that the flow of the river and the level of Lake Ontario must be kept at all times as they would have been if no construction operations had been undertaken. However, it might be possible that a few brief periods of increased or decreased flow might be allowed. These periods would be measured in hours, or, at most, in days. Any such periods would be arranged in advance by all interested parties and compensated by equivalent decreases or increases during subsequent periods so that monthly-mean hydraulic factors would not be altered. Any such periods required are referred to as "emergency".

138. At the initiation of the model study, it was not known to what extent the water level could be raised at the Iroquois Dam* without

* Iroquois Dam is the structure which would be constructed between Iroquois Point and Point Rockaway (see plate 2).

an appreciable effect on the stage-discharge relation at Lake Ontario. (A study of this problem constituted one phase of the model tests of the construction program.)

Construction of the Recommended Plan

139. The construction of the Recommended Plan would be divided into five steps or phases. These five phases are discussed in the paragraphs below.

First step

140. The first construction step would extend over two or more seasons, during which Iroquois Dam would not be ready for service. The principal operations required would be carried on simultaneously (reference is made to plates 38 and 1A (appendix):

a. Required portions of Lalone and Lotus Island would be excavated in the dry, leaving the outer rims of the islands in place. The channel between these islands would be blocked and the area used for spoiling excavated materials.

b. The channels between Galop, Dixon, and Sears Islands would be cofferdammed, and cofferdams would be placed along the swift-water area of the Galop Island north channel to inclose the coves on the north side of Galop Island. Cofferdams would also be built to inclose the area to be excavated between Galop and Tick Islands. Dry excavation in the cofferdammed areas would be carried out during the entire first step.

c. Open-water dredging during the first step would be

limited to dredging at the head of the navigation channel outside of the cofferdam in the vicinity of Butternut Island, the open-water dredging at Chimney Point being deferred until after construction of Iroquois Dam.

Second step

141. The second construction step would involve the use of the Iroquois Dam to prevent excessive discharge and, as far as permissible, to create backwater conditions with greater depths and reduced velocities in the lower portion of the section. It would include the final work in the channel through Galop Island, and also the diversion of flow into this channel and the temporary closure of the Galop Island south channel by cofferdams. These items would be prosecuted simultaneously or in close succession, in the following manner:

a. Dipper dredges would complete the excavation of the lower end of the channel through Galop Island.

b. The cofferdams at the upstream end of Galop Island would be removed and flow diverted into the hydraulic channel, the stage discharge relation being held constant by suitable manipulation of the gates of Iroquois Dam.

c. Simultaneously with the opening of the channel through Galop Island, cofferdams would be constructed to close the Galop Island south channel at Butternut Island and Dead Man's Rapids and the Lotus Island south channel at its lower end. The construction of these cofferdams would be closely coordinated with each other and with the regulation of Iroquois Dam to control water levels at Chimney Point and to facilitate the construction of these closures. Stop-log openings could be

provided in the downstream cofferdams to permit partial drainage of the large inclosed area by temporarily restoring original stages at Iroquois Dam as an emergency measure to save a large amount of pumping.

Third step

142. The third step would include the dry excavation of the unwatered Galop Island south channel. Wet excavation in the vicinity of Chimney Point could be carried on simultaneously, as could such other dredging operations as available plant would permit. These dredging operations are listed below under the fifth step.

Fourth step

143. The fourth step would include the removal of the cofferdams blocking the Galop Island south channel and Lotus Island south channel. Stages at Chimney Point would be controlled during this operation by regulation of Iroquois Dam. Dredging in open water would be continued.

Fifth step

144. The fifth step would include all remaining dredging operations and other minor improvements to be completed. The principal items would be:

a. Dredging in the vicinity of Chimney Point and near the entrance of the Galop Island south channel at Butternut Island.

b. Dredging the downstream ends of the improved Galop Island south and Lotus Island south channels below the cofferdams.

c. Dredging the channel between Cardinal Point and Lalone and Lotus Islands.

d. Removal of minor obstructions along the Galop Island north channel and the construction of other planned improvements.

Construction of the Alternate Plan

145. The construction schedule for the Alternate Plan would be divided into four steps:

First step

146. The first step would require two or more seasons. During the first two seasons Iroquois Dam would not be ready for service; therefore, all operations would be planned to avoid disturbing the stage-discharge relation at Chimney Point. The principal operations required would be:

a. Required portions of Lalone and Lotus Islands would be excavated in the dry, leaving the island rims in place. The channel between the islands would be blocked and the area used for spoiling excavated materials.

b. Simultaneously, the Lalone and Lotus Island south channel would be closed by cofferdams at its upper and lower ends and the channel would be excavated in the dry, spoiling materials on the American mainland. Minor open-water dredging at the lower end of this channel could be carried on advantageously with the downstream cofferdam in place.

c. Dry excavation of the channel through Galop Island would be carried out during this and the succeeding period. Spoil would be placed in the cove just south of the channel between Adams and Galop Islands. Cofferdams would be constructed along the swift water of the Galop Island north channel, closing the coves on the north side of Galop

Island, to permit excavation of this portion of the channel in the dry.

d. The minor channels between Dixon, Sears and Baycraft Islands would be closed by cofferdams, and required portions of the small-island group would be excavated in the dry, leaving the outer rims of the islands in place. Spoil materials would be placed on the remaining portions of the islands and in the shallow water south of the island group in the vicinity of Benedict Island.

Second step

147. The second step would be dependent upon the completion of the Lalone-Lotus Island south channel. Backwater from Iroquois Dam could be utilized, provided the structure had been completed. The following operations would be carried out:

a. Simultaneously with the opening of the Lalone-Lotus Island south channel, the Galop-Dixon channel would be cofferdammed and a cofferdam would be constructed around the area to be excavated between Galop Island and Tick Island. Placement of these structures would be closely coordinated in order to maintain existing stage relationships at Chimney Point. Dry excavation in the navigation channel between Tick Island and Baycraft Island would be continued. The spoil would be deposited south of the cofferdam between Galop and Tick Island, and in the unused portion of the Galop-Dixon channel.

b. Available equipment could be used in open-water dredging operations in the navigation channel between Chimney Island and Galop Island.

c. With backwater available from the completed Iroquois Dam,

further dredging in open water could be carried out in the navigation channel below Sears Island and opposite Lalone and Lotus Islands, including the removal of the remaining rims of these islands.

Third step

148. The third step would include the final work on the navigation channel through Galop Island, and the diversion of flow into this channel. It would involve the use of Iroquois Dam to prevent excessive discharge and to create backwater conditions with greater depths and reduced velocities in the lower portions of the section. The operations involved would be carried out simultaneously or in close succession, and would include the following:

a. Dipper dredges would complete the excavation at the lower end of the channel through Galop Island, including the removal of the remaining rims of the small-island group in that vicinity. This operation would be facilitated by reduced velocities obtained by backwater from Iroquois Dam.

b. The cofferdam at the head of Galop Island would be removed, flow thereby being diverted into the navigation channel through Galop Island. This would require skillful use of Iroquois Dam to avoid affecting the stage-discharge relation at Chimney Point, particularly when the first breach is made in the cofferdam. "Emergency" use of the dam to secure slack water in this region might be desirable at this time.

c. Open water dredging operations (b and c of the preceding step) would be continued during this period.

Fourth step

149. The fourth step would include all remaining dredging operations and the removal and construction of minor improvements not previously completed. The principal items would be:

a. Removal of the cofferdam along the north side of Galop Island, the excavation required to remove the remainder of the points of Galop Island, and the excavation necessary to provide project depth north of the cofferdam location.

b. Completion of dredging operations in the navigation channel at Drummond Island.

c. Construction of the training dike at the head of Galop Island.

d. Removal of Lock 26, with the excavation required in this immediate vicinity.

e. Removal of Spencer Island Pier.

f. Removal of Gut Dam.

g. Removal of Locks 27 and 28.

Model Tests of Natural River Controls

150. The model proved useful in determining the effects of several critical construction operations upon the stages at Chimney Point. The first item determined was the effect of raising the backwater at Iroquois Dam with the river in natural condition. Operation of the dam was simulated by manipulation of the model tailgate. For each of three discharges (180,000, 255,000, and 310,000 cfs) the tailwater was raised by small increments until approximately a 1-ft rise occurred at Chimney

Point (gage 1). Plates 115, 116, and 117 show the water-surface profile for each change in stage at gage 6. Plates 118, 119, and 120 present, in rating curve form, the effects of raising the water-surface elevation below Lotus Island on several of the gages located within the model limits. As would be expected, the main controls were in the Canadian and American Rapids. However, secondary controls were exercised by the Lalone and Lotus Island south channel, Dead Man's Rapids and the Galop-Dixon channel. This may be noted by comparing the rating curves for gages 13 and 5 (Galop Island south channel) with rating curves for gages 11 and 12 (Galop Island north channel) (see plates 118, 119, and 120).

Model Tests of Recommended Plan Construction Steps

Effects of cofferdam

151. The construction program for the Recommended Plan was tested as an integral part of Recommended Plan as designed. The first tests conducted were made to determine the effect of placement of the cofferdams inclosing the hydraulic channel and those between Galop, Tick and Butternut Islands (see plate 121 for cofferdam locations). Plate 122 shows the effects of these cofferdams upon the stages at Chimney Point and Ogdensburg, as well as other selected gages. Although the closure of the Galop-Dixon Islands channel under the construction program would occur later, little if any effect could be noted from the installation of this cofferdam. Plate 123 shows the effects of the cofferdams upon the discharge distribution. A comparison of the curves on this plate with the corresponding discharge distribution obtained on the base tests (plate 10) shows that only slight changes were effected in the two Galop

Island channels, that the flow through the Lalone and Lotus Island north channel was decreased by about 5 percent, and that the flows through Dead Man's Rapids and the Lalone and Lotus Island south channel were increased. Plate 124 shows velocities obtained with the cofferdams installed. A comparison with base test velocities (plates 11, 12, and 13) will show that the cofferdams had little effect on velocities above Galop Island. However, increased velocities were noted along the cofferdam. There was little increase in velocities in the channel below Lock 28.

Critical construction phase

152. The diversion of flow from the Galop Island south channel to the hydraulic channel (items b and c of second step, paragraph 139) has been referred to as the "critical construction phase." Two methods have been proposed for the control of the flow diverted from the Galop Island south channel into the hydraulic channel:

a. Control of lake level and discharge by manipulation of Iroquois Dam.

b. Control of lake level and discharge by a stop-log control dam installed in the hydraulic channel. "Method a" was recommended under the original construction schedule while "method b" was proposed by the Experiment Station during the model testing program. Model studies of the two methods are discussed below.

153. Lake-level control by Iroquois Point Dam. Tests were carried out in the model to determine the optimum water-surface elevations at Iroquois Dam (or rather, at gage 6) to maintain levels at Chimney Point or Ogdensburg. Without changing the natural tailwater elevation at gage

6, the Galop Island south channel was closed by cofferdams from Galop Island to Tick Island to Butternut Island to the American mainland, while simultaneously the hydraulic channel was opened to flow by removing the upper and lower cofferdam plugs. Flow in the model was then allowed to become stable under this new regimen and all gages were read. The model was then returned to the initial conditions (immediately prior to diversion), the tailwater was raised slightly, and the diversion procedure repeated. This operation was repeated several times, progressively increasing the tailwater elevation each time, until the Ogdensburg gage after diversion showed an elevation slightly higher than that for natural river conditions. The above procedure was followed for each of the three discharges. With the data thus obtained, rating curves for all three discharges were prepared by plotting elevations at gage 6 against the resulting elevations at Ogdensburg both before and after diversion. These rating curves are shown on plate 125. It will be noted from these curves that elevations ranging from 240.30 to 242.90 would be required just below Lotus Island (gage 6) to maintain Lake Ontario levels during this critical construction phase.

154. Lake-level control by stop-log structure. Under this method of regulation it was assumed that Iroquois Dam would not necessarily be in operation; therefore, the water-surface elevation below Lotus Island (gage 6) remained at the natural river elevation corresponding to each discharge. Constriction of the hydraulic channel was accomplished in the model by means of sheet-metal strips (representing the stop-log structure) extending from the right bank of the channel. This constriction was effected from one side only. The operating procedure was similar to that

described above, except that varying lengths of constriction were employed until a normal elevation at Ogdensburg was obtained. With the data thus obtained the rating curves on plate 126 were prepared. These curves show that clear openings varying from 250 to 400 ft, depending upon the river discharge, would be required to maintain normal levels in Lake Ontario. The use of this method would allow partial drainage of the Galop Island south channel prior to closure of the lower cofferdams.

155. In both of the above series of tests the cofferdam along the coves of Galop Island remained in place. With the control at Iroquois Dam this structure made little difference. However, if the stop-log control method were used it would probably be advisable to remove this cofferdam, because of a water-surface differential between the hydraulic channel and the Galop Island north channel which produced adverse current directions.

Model Tests of Alternate Plan Construction

156. No formal testing of the construction program for the Alternate Plan was undertaken. However, the cofferdam locations around Galop Island for the Recommended Plan were very similar to those used for the Alternate Plan, and the results obtained for the latter should be generally applicable to both.

157. There was, however, one feature of the Alternate Plan which was not paralleled in the Recommended Plan, that is, excavation of the Lalone and Lotus Islands south channel. Tests were conducted to determine the effect of cofferdamming this channel for discharges of 255,000 and 310,000 cfs. These tests revealed that the effect upon stages at

Chimney Point was negligible, rises of only 0.16 ft and 0.08 ft being noted for discharges of 310,000 cfs and 255,000 cfs, respectively.

PART IX: SUMMARY OF RESULTS

General discussion

158. The model study of the Galop Rapids section of the St. Lawrence River made valuable contributions to the hydraulic design of this highly complicated engineering project. At the initiation of the study, the role of the model was one of checking certain proposed designs and furnishing additional data from which a final design could be perfected. However, the model study far exceeded these initial expectations insofar as the development of a satisfactory design is concerned. Furthermore, it is felt that the study provided a basis for further hydraulic computations in connection with this or similar hydraulic design problems.

Model verification

159. The verification of the model was a particularly important phase of the study resulting in an accurate reproduction of the water-surface profiles, discharge distributions, and current directions of this reach of the St. Lawrence River. One valuable by-product of this phase was the correction and amplification of the existing prototype data which has resulted in a broader knowledge of the hydraulic characteristics of this and other reaches of the river. The model verification also served to indicate the general degree of accuracy to be expected in subsequent phases of the study.

Model base tests

160. The model base tests (of natural river conditions) also

served the purpose of augmenting and expanding the available hydraulic data, which will simplify and strengthen any future backwater computations found necessary in connection with the project.

Revised Recommended Plan

161. Tests of the Recommended Plan as designed have been discussed in foregoing parts of this report. Step 13 of the Revised Recommended Plan produced velocities generally comparable with those of the Final Alternate Plan. The revised Recommended Plan, Step 13, is with the exception of a small section of channel below Dixon Island, a generally acceptable two-channel project providing one channel for upstream and one for downstream traffic.

Final Alternate Plan

162. The Final Alternate Plan as developed in the model generally satisfied the interpretation of the prescribed velocity criteria, which stated that under the most adverse condition most of the spot velocities should be under 5.0 ft per sec with none of the velocities over 5.25 ft per sec. To carry out this interpretation under the condition of minimum lake level and maximum discharge, the plan was designed to produce velocities in excess of 5.0 ft per sec through the Galop Island cut and opposite Cardinal Point, while velocities in the Drummond Island channel were generally not more than 5.0 ft per sec. Since velocities up to 5.25 ft per sec are permissible, additional reductions in cross-sectional area of the latter channel are possible.

163. The excavation of the point on the American mainland opposite the head of Galop Island was of very small value from the standpoint of

velocity reduction. Removal of this point resulted in a velocity reduction of less than 0.1 ft per sec.

164. Modification of the Galop Island cut by lowering the grade and decreasing the width would be permissible, to the extent indicated by the results of tests of the various step-5 and step-6 modifications.

165. Experiments conducted in connection with the relief cut at Lalone Island indicated that excavation in this area cannot be reduced without a resultant increase in velocities in the Galop Island cut.

PART X: ACKNOWLEDGEMENTS

166. The Galop Rapids model study was conducted under the general supervision of Col. A. B. Jones, CE, formerly District Engineer of the St. Lawrence River District, later District Engineer of the New York District and Jacksonville District. Mr. Vincent R. Stirling, Engineer, formerly of the St. Lawrence River District, was stationed at the Experiment Station as consultant and liaison agent of the District Engineer from June 1943 until his retirement from the government service in April 1944. Mr. Willard F. Simpson, Engineer, formerly of the St. Lawrence River District, replaced Mr. Stirling as consultant and liaison agent and remained at the Experiment Station throughout the remainder of the model testing program and the preparation of the final report.

167. Other engineers who at various times served as consultants and took part in conferences on the model study were: Mr. W. H. McAlpine and Mr. John C. Harrold of the Office, Chief of Engineers; Mr. Guy A. Lindsay of the Canadian Department of Transport and member of the St. Lawrence Advisory Committee; Mr. Gerald V. Cruise, Executive Secretary of the Power Authority of the State of New York and member of the St. Lawrence Advisory Committee; Mr. Hendry of the Ontario Hydroelectric Power Commission Committee; Mr. Frank P. Fifer of the North Atlantic Division, CE; Mr. Don C. Bondurant of the Albuquerque District; and Mr. Lawrence Seaman of the Cincinnati District, CE. The last three named engineers were formerly of the St. Lawrence River District.

168. The model study was conducted by the Hydraulics Division of the Waterways Experiment Station. Engineers actively connected with the

study were: Mr. Joseph B. Tiffany, Jr., Technical Executive Assistant to the Director; Messrs. George B. Fenwick, Ernest B. Lipscomb, and Shields E. Clark, Jr., who was Project Engineer in direct charge of the model construction and the entire testing program.

169. This report was prepared by Mr. George B. Fenwick with the very able assistance of Mr. Willard F. Simpson from a rough draft prepared by Mr. Shields E. Clark.

170. The following appendix, which deals with the economic and other aspects of the various plans tested in the model, was prepared by Mr. Willard F. Simpson, who also made the economic studies discussed therein.

APPENDIX: COMPARISON OF PLANS

Introduction

1. This appendix presents a discussion of the results of model studies of two proposed plans for improving the section of the St. Lawrence River between Chimney Point and a point a short distance below Lotus Island Feature No. 1 of the 1942 Project Report (Mile 67 to 74). The estimates included in this discussion are for purposes of comparing various plans and do not constitute an estimate of the cost of the work. The estimates do not include engineering and contingencies. The engineers of the St. Lawrence River District engaged in the preparation of preliminary plans for improving the International Rapids Section were cognizant of the fact that their designs of hydraulic channels based on incomplete data would possibly require revision when subjected to model tests. The model studies of the Galop Rapids Section were instituted with a view not only of testing the proposed plans but also of developing the most economical solution of the problem. For this reason it was deemed advisable by the District Engineer to conduct economic studies in connection with the model tests. A cost analysis of each plan proposed for testing in the model was made by an engineer familiar with the St. Lawrence River Project and economy was a governing factor in the design of all plans tested.

Design criteria

2. The criteria used during the model studies for guidance in the design of plans and the preparation of cost analyses were the same as

those used by the St. Lawrence River District while studying the project during 1941-42. A slope of one on two was used in all earth cuts, in rock cuts the slope was one on one. The slope used on dikes and spoil dumps was one on two. The bottom grades in navigation channels were designed to provide a 27-ft depth, except in rock cuts where the depth was 30 ft to correspond to the depth over the sills of the locks in this and other sections of the waterway. One foot of over depth was included in both earth and rock quantities. While the 1942 Final Report did not specifically mention the 30-ft-depth feature in rock cuts, the Engineering Annex of the International Agreement specified that all lock sills shall have a depth of 30 ft with the view of providing at a later date for a 30-ft depth in all navigation channels with minimum cost. It is believed to have been the understanding of all engineers connected with the project in recent years that the 30-ft depth would also apply to any other feature which would be difficult to deepen with the project in operating condition. This criterion was followed in the Massena Office in designing the navigation channels and estimating costs, with the view of providing for future deepening at minimum cost, since this policy would permit the excavation of practically all ledge rock in the dry in cofferdams to 30-ft depth plus the 1-ft over-depth allowance.

Plans presented in 1942 Report

3. In the St. Lawrence River Project Report of 1942, prepared by the Massena, N.Y., Office, two plans were presented for improving the Galop Rapids Section. These were called the Recommended Plan and the Alternate Plan. The Recommended Plan was a modification of the original

Canadian Controlled Single Stage Project, the principal features being a winding channel through the American Rapids and a hydraulic cut through Galop Island. The outstanding feature of the Alternate Plan was the wide, practically straight channel through Galop Island which would serve both navigation and hydraulic purposes. The estimated cost of the Recommended Plan amounted to $20,058,000 and the Alternate Plan was estimated at $40,044,000 exclusive of engineering and contingency charges. In summing up the relative merits of the two plans, the principal advantage of the Recommended Plan was its lower cost while the Alternate Plan presented a wide straight channel through this reach, a distinct advantage from the standpoint of navigation. In relation to their effects on power development, the two plans were nearly equal, a small advantage in head accruing to the Alternate Plan.

Unit prices

4. The cost estimates presented in the 1942 Report reflect war-time prices and an emergency construction schedule. Since the estimates in this appendix are based on a normal construction schedule during peace time, a reduction in unit prices is considered permissible. A board of engineers was appointed in 1944 to review the unit prices used in the 1942 Final Report; the following table shows the revised prices compared with those used in 1942.

Classification	1944 Revised Unit Prices Normal Construction Program(1942 Basis)	1942 Report Unit Prices Emergency Construction Program 1942 Final Report
Dry Earth	$0.40 per cu yd	$0.50 per cu yd
Dry Rock	1.25 " " "	1.70 " " "
Wet Rock	7.00 " " "	7.00 " " "
*Wet Earth	0.85 " " "	0.75 " " "

* Classified as dipper dredging in 1942 Report

Added Information

5. During verification tests on the model there were indications that errors existed in the prototype data, and subsequent investigations verified these indications. Surveys conducted in connection with these investigations during 1943 disclosed that the maps on which the design of improvement plans by the Massena Office were based, contained errors in rock elevations and river depths. The Rock Contour Map, Vicinity of Galop Island, dated January 1942, and the Hydrography and Topography Map, File No. SC-1-534/2 dated March 1942, were revised to incorporate these corrected data, and plans and cost estimates prepared in this office have been based on the corrected drawings. Subsurface exploration in this region is still incomplete, and considerable additional exploration work should be performed before final designs and cost estimates are prepared.

Application of revised prices and added information

6. The differences between the original and revised unit prices were relatively small and caused only minor changes in estimated costs.

7. Total excavation quantities based on the revised maps varied only slightly from those computed from the original maps, but the relative amounts of earth and rock reflect the effects of the added data to

a marked degree. This is particularly true in the Recommended Plan where the increase in rock excavation was enormous.

8. A relocation of the construction cofferdam system based on the revised maps reduced the estimated quantity of wet rock excavation, effecting a considerable diminution in the cost of both plans. An analysis of the construction program for the Alternate Plan indicated the advisability of including an item in the cost estimate to cover the construction and dewatering of cofferdams.

Revised cost estimates based on new prices and data

9. In order to compare the construction costs of plans developed by model study on the basis of corrected maps and revised unit prices, with cost estimates in the 1942 St. Lawrence Final Report, the latter estimates have been revised in the light of the changed conditions.

10. In the Recommended Plan, the revision of the unit prices reduced the estimated cost of the work approximately 1.33 million dollars. The change in excavation quantities based on the revised data increased the total by about 2.25 million cubic yards, the rock excavation being increased by 5.00 million yards and the earth excavation decreased by 2.75 million cubic yards. The redesign of the cofferdams reduced the estimated quantity of wet rock excavation, a difficult and expensive item of work, by 0.33 million yards, a saving of approximately 2.25 million dollars. The cumulative effect of the above changes resulted in an increase of approximately 1.75 million dollars in the estimated cost of constructing the plan. The following tables show a comparison of the original and revised quantities and costs for this plan:

Comparison of Excavation Quantities

Classification	Revised Estimate Based on Revised Data March 1944 C. Y.	Original Estimate Based on Old Data 1942 Final Report C. Y.	Difference C. Y.
Dry Earth	10,803,000	13,255,000	-2,452,000
Dry Rock	6,615,000	1,591,000	+5,024,000
Wet Rock	153,000	472,000	- 319,000
*Wet Earth	7,255,000	7,229,000	+ 26,000
Totals	24,826,000	22,547,000	+2,279,000

*Classified as dipper dredging in 1942 Report

Comparison of Costs

Cost based on quantities from 1942 report; unit prices from 1942 report	$20,057,950
Cost based on quantities from 1942 report; 1944 unit prices	18,739,400
Cost based on quantities computed from revised data; 1942 unit prices	25,159,250
Cost based on quantities computed from revised data; 1944 unit prices	21,827,750

Engineering and contingencies are not included in the above estimate.

11. In the Alternate Plan, the revision of unit prices reduced the estimated cost of the work less than 1 million dollars. The revised estimate of excavation quantities, based on the additional data, increased the total approximately 1.33 million yards, including a relatively small increase in rock excavation. The relocation of the cofferdams reduced the estimated quantity of wet rock excavation by more than 1.33 million cubic yards; the quantity of wet earth was reduced approximately 3 million yards. The cumulative effect of the changes including the item for cofferdams results in a decrease of approximately 7 million dollars in the estimated cost of constructing the plan. The following tables show a comparison of the original and revised quantities and costs for this plan:

Comparison of Excavation Quantities

Classification	Revised Estimate Based on Revised Data March 1944 C. Y.	Original Estimate Based on Old Data 1942 Final Report C. Y.	Difference C. Y.
Dry Earth	19,030,000	16,655,000	+2,375,000
Dry Rock	7,953,000	4,594,000	+3,356,000
Wet Rock	0	1,412,000	-1,412,000
*Wet Earth	17,017,000	20,023,000	-3,006,000
Totals	44,000,000	42,687,000	+1,313,000

*Classified as dipper dredging and hydraulic dredging in 1942 Report.

Comparison of Costs

Cost based on quantities from 1942 report; unit prices from 1942 report	$40,043,650
Cost based on quantities from 1942 report; 1944 unit prices	39,311,800
Cost based on quantities computed from revised data; 1942 unit prices	35,797,850
Cost based on quantities computed from revised data; 1944 unit prices	33,017,700

Engineering and contingencies are not included in the above estimates.

Development of Revised Recommended Plan Step 13

12. Model studies of the Recommended Plan indicated velocities above the prescribed criterion in the navigation channel, thereby necessitating a redesign of the channels. Based on model data and the revised topographic data, the hydraulic channel was enlarged and extended to increase discharge, and the navigation channel was realigned to reduce rock excavation. This design was called the Revised Recommended Plan and the estimated cost of construction amounted to $18,257,000. Tests of this plan in the model showed that it was an improvement over the original design but velocities were still high at several points in the navigation channel. Increases in channel width in the vicinity of these points in

an effort to obtain more uniform velocities through this channel were only partially successful. As the model studies proceeded, it became apparent that the most economical method of reducing velocities in the navigation channel would be to enlarge the hydraulic cut. This was due to the fact that excavation in the latter cut was largely earth while rock predominated in the former channel. The final step in the development of this plan to a degree which would satisfy the design criteria was Revised Recommended Plan Step 13. The estimated cost of construction of this plan was $22,158,000, an increase of $3,901,000 over the cost as originally designed. The principal difference between the step-13 design and the Revised Recommended Plan was that the former provided two navigation channels which will be useful in separating upbound and down-bound steamer traffic. The disadvantages of the plan, as compared with the Final Alternate Plan, were the greater cost, more difficult construction procedure, and less desirable channel alignment for navigation.

Development of Final Alternate Plan

13. Model studies of the Alternate Plan indicated that the removal of the dikes would reduce velocities in the navigation channel considerably below the design criterion indicating that the plan was over designed. Accordingly, a series of plan modifications was designed for model testing, progressively reducing the channel widths. The various steps of this procedure are covered in the main body of this report.

14. A reduction in the width of the Drummond Island channel from 1600 ft to 1400 ft increased velocities only a small amount and indicated that a further reduction was feasible, but further study of this channel

was deferred pending development of the Galop Island channel. The initial reduction of 150 ft in the width of the Galop Island cut produced velocities which closely approached the maximum desired. The plan containing these two revisions, called the Alternate Plan, Step 2, (see plate 79) satisfied the design criteria and represented a reduction in estimated cost amounting to more than 7 million dollars. In the next plan tested, Alternate Plan Step 3, (see plate 80), the Galop Island cut was reduced an additional 150 ft to 1300 ft, resulting in a reduction in estimated cost amounting to 1.75 million dollars, but velocities in the channel were above the criteria, indicating that additional area was necessary. In Step 4 (see plate 81) the additional channel area was provided, increasing the estimated cost over that of the preceding step by 1.33 million dollars. Velocities produced by this plan were within the maximum desired, and the estimated cost was 0.5 million dollars below any other satisfactory plan tested. Analysis of model data and study of hydrographic and topographic maps indicated that further reduction in the cost of constructing the Galop Island cut was not feasible if the present alignment were followed, but model studies together with economic analyses had thus far indicated a cost reduction of more than 7.5 million dollars with the possibility of further reduction.

15. The alignment of the Galop Island cut in the Alternate Plan was influenced by the emergency wartime construction program which contemplated its construction prior to completion of the control dam. In order to follow the proposed program, it was desirable to avoid excavation in swift water insofar as possible, and the cut was located with this in view. Since the emergency no longer exists, the construction

program can now be adjusted to normal construction procedure permitting the deferment of excavation in swift water until backwater from the control dam can drown out the rapids, thus making it feasible to shift the channel to the north to take advantage of the deep holes in the Canadian Galop Rapids to reduce excavation. This feature is incorporated in the design called Alternate Plan Step 5 (see plate 82), which was the next plan studied in the model. Tests of this plan demonstrated that both the Galop Island cut and the Drummond Island channel were over-designed, indicating possible reductions in excavation and costs. The estimated cost of constructing this plan was $25,708,000, or only $400,000 more than the Step 4 plan, thus the model study was leading to reduced costs at each step tested.

16. The size of the cuts in Step 5 were progressively reduced until the design called Step 6B (see plate 92) was reached. The estimated cost of constructing this plan was $19,775,000, a reduction of $13,243,000 when compared with the cost of the Alternate Plan. Model tests of the 6B plan produced velocities above the prescribed criterion between the head of Galop Island and Cardinal Point. A method of revising this plan to reduce objectionable velocities will be discussed hereinafter.

17. It was evident at this stage that the channel reduction program in the Galop cut had passed the critical point and that the satisfying of the design criteria would require small increases in area, together with other modifications. The resulting design was called the Final Alternate Plan, and model tests produced results that generally satisfied the velocity criterion. The estimated cost of this plan was

$21,497,000 and analysis of the results of the model studies indicates that further reduction may be possible. This feature will be discussed hereinafter.

Spoil areas

18. Considerable study has been devoted to the economical disposal of material excavated from the cuts, since this problem has a direct bearing on the cost of the work. In order to avoid excessive heights of spoil dumps for the large quantity of dry material to be excavated, the possibility of increasing the size of these areas by dumping in the river was studied in the model. The proposed spoil areas which were studied are shown on plate 88, and they would provide ample room for spoil disposal at nominal heights. The major spoil disposal problem is that of wet earth (dipper dredging). Three wet-earth disposal areas for the Final Alternate Plan were tested in the model. The use of the areas adjacent to Chimney Island and Drummond Island, designed to accomodate material dredged from the Drummond Island channel would require extensive rehandling equipment. Since model tests showed the dike along the south edge of this channel between Chimney and Tick Islands to be unnecessary for the proper functioning of the plan, and in view of the revised construction schedule which contemplates excavation of the greater portion of this channel after Iroquois Dam can be used to reduce river velocities, it is proposed to deposit the spoil in the deep water above Ogdensburg, using ordinary dump scows for transportation. The minimum cross-sectional area of the river at this proposed dump ground is approximately 250,000 sq ft, and 10,000,000 cubic yards of spoil would reduce this area only 17% to 208,000 sq ft. The area of the river opposite Ogdensburg is approximately

165,000 sq ft and opposite the Lower Lake Terminals is only 160,000 sq ft, indicating that the proposed spoil dump would not materially affect velocities in this section of the river. A minimum depth of 35 ft is proposed over the top of the spoil dump. This dump area was not tested in the model.

19. Observation in the model of the flow pattern in the vicinity of Frazier Shoal with the Final Alternate Plan installed indicated that the deep channels in this area could be used for disposal of wet earth without seriously affecting the velocities in the navigation channel. As stated in the main body of this report, velocities in the navigation channel opposite the proposed spoil area would not be adversely affected, but its possible effects at Sparrowhawk Point can only be assumed to be negligible. With the Iroquois Dam in operation, wet earth could be deposited in this area by dump scows and the length of haul would be very short. This is one of the cheapest methods of handling dredging spoil, and this is the only area in the vicinity suited to this type of operation. The capacity of the proposed area is approximately 4,000,000 cubic yards which would accomodate all dredging spoil from operations in the vicinity.

20. Proposed spoil areas for the Revised Recommended Plan are very similar to those for the Alternate Plan with the following exceptions: a small area was added below Chimney Point and the area adjacent to Drummond Island was omitted. These spoil areas did not adversely affect the velocities in the channels.

Velocity criteria

21. It is believed the present velocity criteria governing the

design of the Galop Rapids channels are more stringent than those in other waterways carrying similar traffic. Less conservative criteria would permit further reductions in channel widths and considerable savings in construction costs. Velocities of 8 ft per sec are not uncommon in Montreal Harbor and the current in the rapids section of the St. Clair River at Port Huron, Michigan, flows at 7.3 ft per sec where the channel is 600 ft wide. There are many such instances where steamers navigate continually in currents well above 6 ft per sec. With these facts in view, it appears that present velocity criteria are unnecessarily restrictive. This is particularly true when it is considered that the maximum allowable velocities governing the design are for the worst possible operating conditions and that these conditions, based on previous records, will not occur more than one percent of the time under the prescribed rules for regulating the river discharge and lake level. In view of the wide, relatively straight navigation channel to be provided through the Galop Rapids Section, which will permit steamers to avoid the swift currents near the middle of the channel, a review of the velocity criteria with a view of liberalizing appears to be in order. Reference to plate 114 will show the relatively small part of the time that steamers will be subjected to the high velocities even though they operate in the swiftest currents.

Discussion

22. As has been pointed out, the most economical design studied in the model was Step 6B of the revisions to the Alternate Plan. Although a few of the velocities in this plan were somewhat above the

maximum prescribed, it is possible to select an upbound steamer lane 300 ft wide which would permit traffic to operate in currents at or below the prescribed maximum velocity except in a short reach above Galop Island. A small amount of dry earth excavation in the section where the excessive velocities occurred would lower the velocities and add very little to the cost of construction. The alignment of the upbound lane is superior to that provided in the Revised Recommended Plan. In view of the fact that during the greater part of the time traffic would not have to follow this less desirable lane to avoid swift currents, it appears that consideration should be given to the adoption of such a plan.

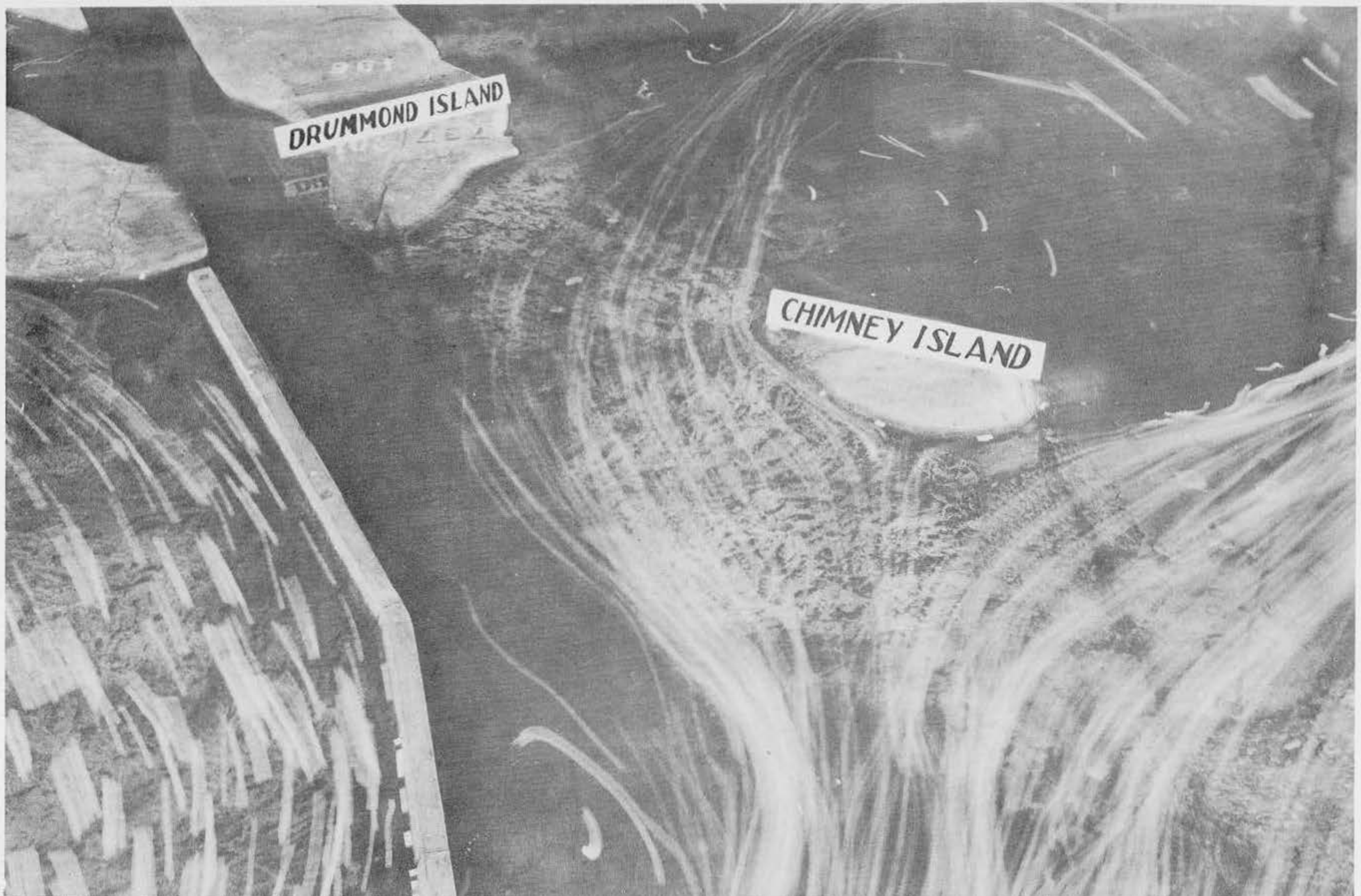
23. With reference to the Final Alternate Plan, it is pointed out that studies of refinements of this plan were not carried to a final conclusion. Reference to plates 105 to 109 will show that velocities in the Drummond Island channel were below the maximum allowed, indicating the possibility of further reduction in width. Analysis of the test data will show that the cut on the American mainland near the head of Galop Island had a very minor effect on the velocities at the entrance to Drummond Island channel; it is possible that equal or better results could be secured by a small amount of excavation in the channel proper. It is possible that the velocities at the entrance to the Galop Island channel could be reduced by lowering the grade in the vicinity of the Galop training dike. There are other similar points which were not fully investigated, but by means of computations based on the data furnished by the model studies, it is believed that satisfactory answers can be obtained and the cost further reduced.

PHOTOGRAPHS

Base tests -- downstream view, vicinity of Spencer Island Pier

PHOTOGRAPH 1

PHOTOGRAPH 2



Base tests -- downstream view, vicinity Chimney Island

PHOTOGRAPH 3

Base tests -- downstream view, vicinity of Butternut and Tick Islands

Base tests — downstream view, vicinity of Gut Dam

PHOTOGRAPH 5

Base tests -- downstream view of Galop Island north channel

PHOTOGRAPH 6

Base tests -- downstream view of Galop Island north channel, vicinity of Dixon Island

PHOTOGRAPH 7

Base tests -- downstream view of Galop Island south channel

PHOTOGRAPH 8

Base tests -- downstream view, vicinity of Lalone Island

PHOTOGRAPH 9

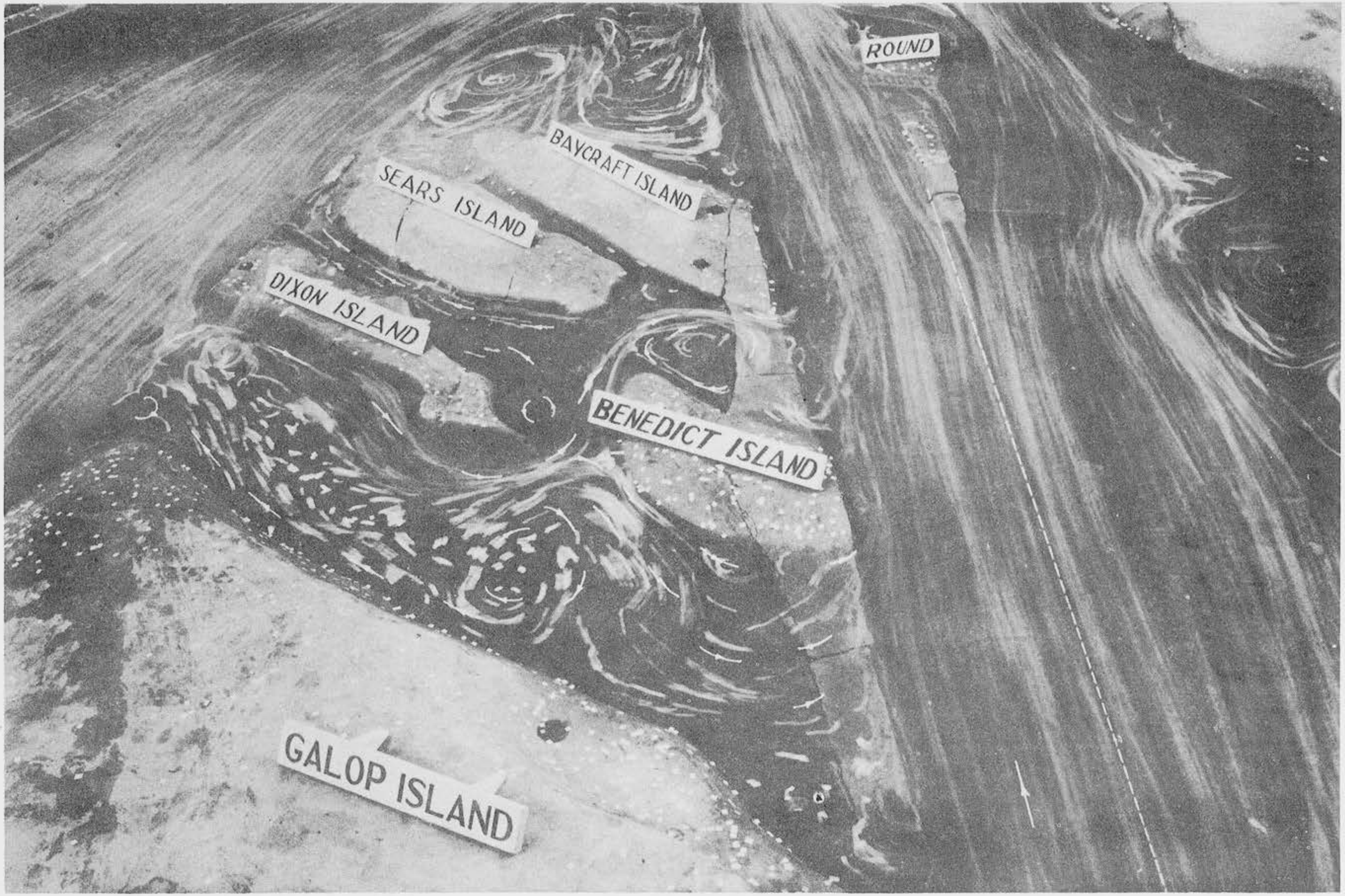
Recommended Plan -- downstream view of navigation channel at Chimney Point

PHOTOGRAPH 10

Recommended Plan -- downstream view, vicinity of Butternut Island

Recommended Plan -- downstream view, head of Galop Island

PHOTOGRAPH 11



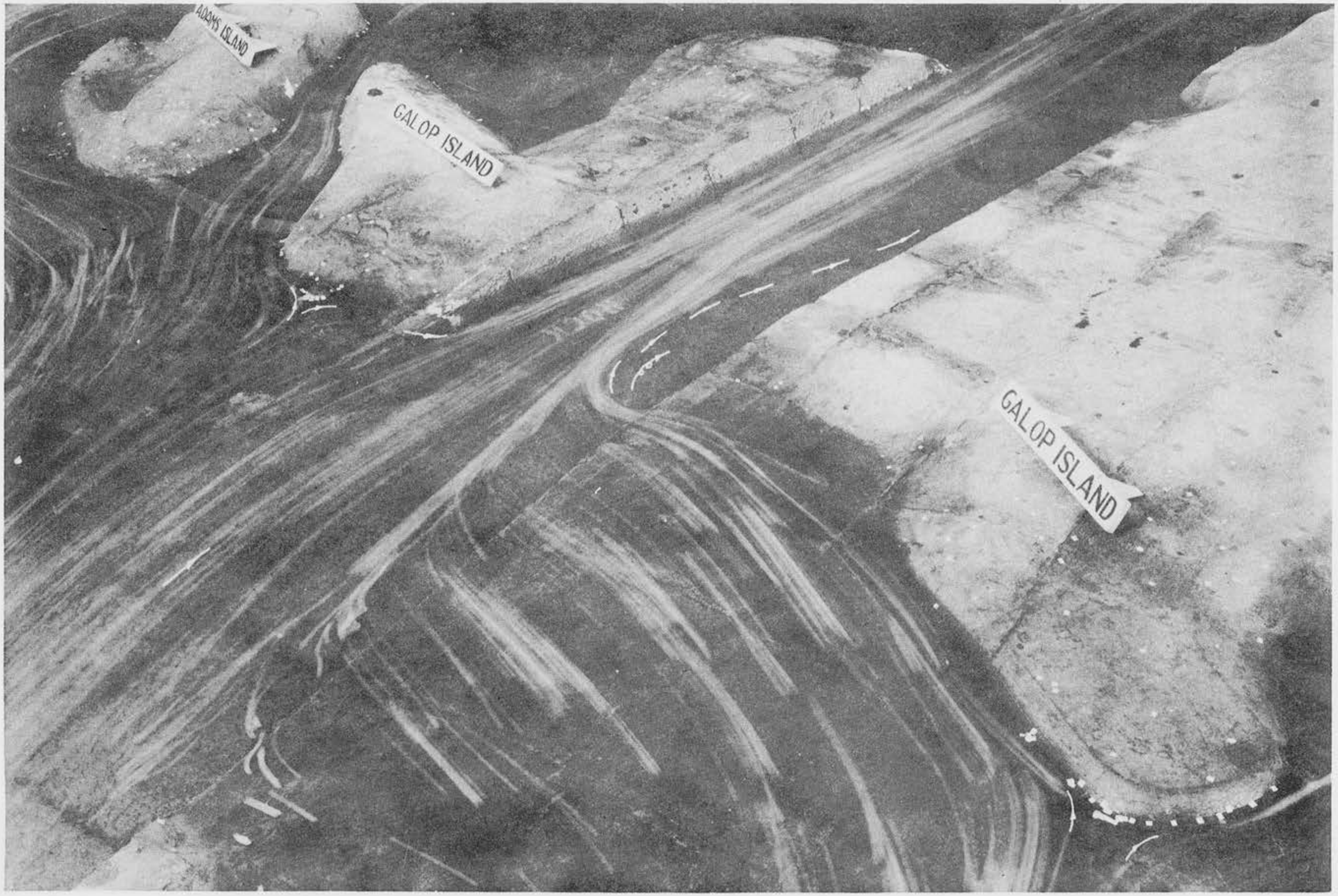
Recommended Plan -- downstream view, lower end of Galop Island

PHOTOGRAPH 13

Recommended Plan — downstream view of navigation channel at Galop Island

PHOTOGRAPH 14

Recommended Plan -- downstream view, vicinity of Lalone and Lotus Islands



Recommended Plan -- downstream view of hydraulic channel through Galop Island

PHOTOGRAPH 15

PHOTOGRAPH 16

Recommended Plan — downstream view, vicinity of Adams Island

PHOTOGRAPH 17

Recommended Plan -- downstream view of hydraulic channel, vicinity of Dixon Island

Alternate Plan -- downstream view of navigation channel, vicinity of Drummond and Chimney Islands

PHOTOGRAPH 19

Alternate Plan -- downstream view of navigation channel, vicinity of Butternut Island

Alternate Plan -- downstream view of navigation channel through Galop Island

PHOTOGRAPH 21

Alternate Plan -- downstream view of navigation channel through Galop Island

PHOTOGRAPH 22

Alternate Plan -- downstream view, vicinity of Benedict and Baycraft Islands

Alternate Plan -- downstream view, vicinity of Lalone and Lotus Islands

PHOTOGRAPH 23

PHOTOGRAPH 24

Alternate Plan -- downstream view of Galop Island north channel and navigation channel at lower end of Galop Island

Improved Alternate Plan -- downstream view, vicinity of Chimney Point

PHOTOGRAPH 26

Improved Alternate Plan -- downstream view, vicinity of Drummond and Butternut Islands

PHOTOGRAPH 27

Improved Alternate Plan -- downstream view at head of Adams and Galop Islands

PHOTOGRAPH 28

Improved Alternate Plan -- downstream view of navigation channel at lower end of Galop Island

PHOTOGRAPH 29

Improved Alternate Plan -- downstream view, vicinity of Lalone and Lotus Islands

PHOTOGRAPH 30

Improved Alternate Plan -- downstream view, vicinity of Butternut Island

PHOTOGRAPH 31

Improved Alternate Plan -- downstream view of Galop Island south channel, head of Galop Island

PHOTOGRAPH 32

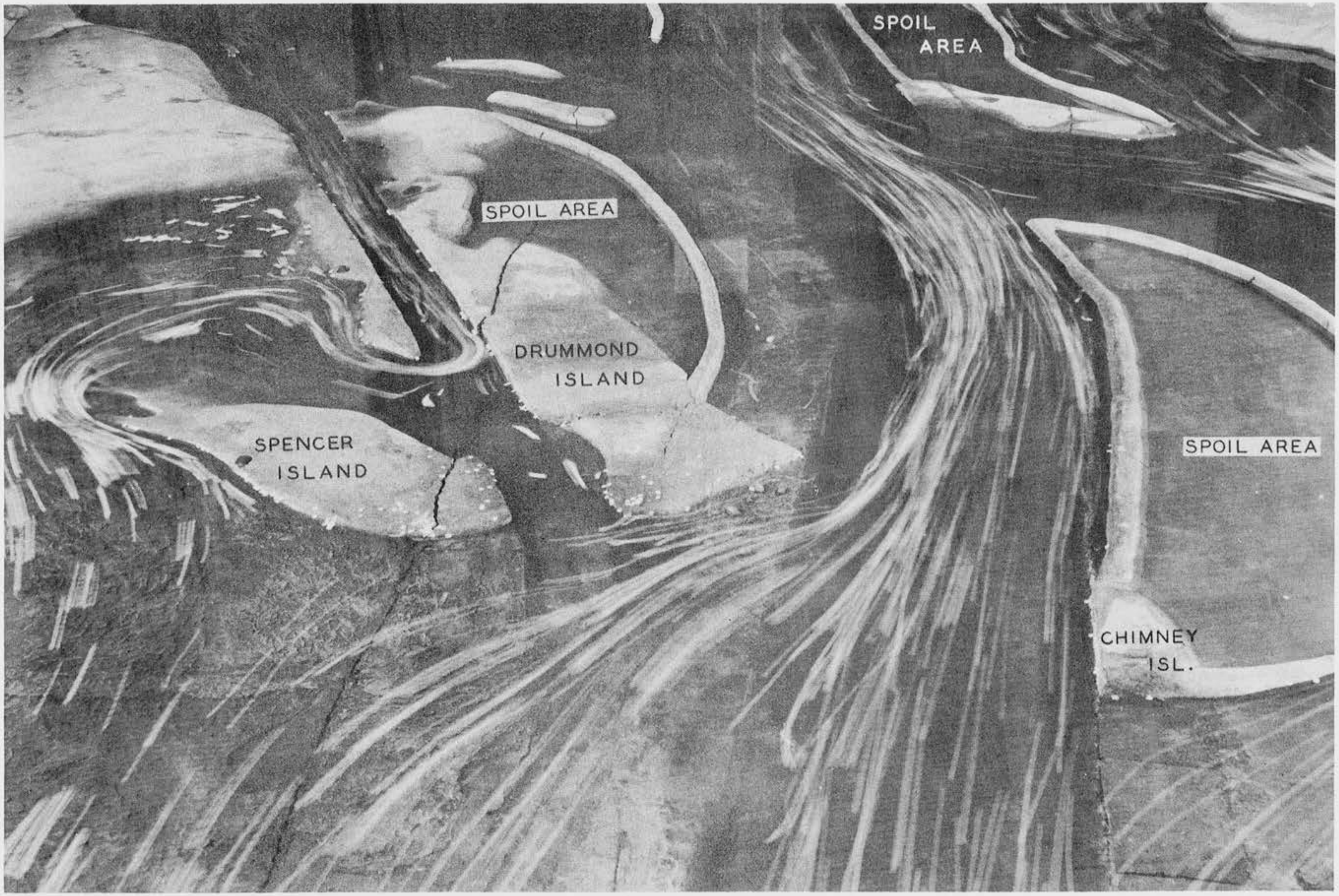
Improved Alternate Plan -- downstream view of Galop Island south channel, lower end of Galop Island

PHOTOGRAPH 33

Improved Alternate Plan -- downstream view, vicinity of Benedict and Lalone Islands

PHOTOGRAPH 34

Final Alternate Plan -- downstream view, Chimney Point channel



Final Alternate Plan -- downstream view, Drummond Island channel

PHOTOGRAPH 35

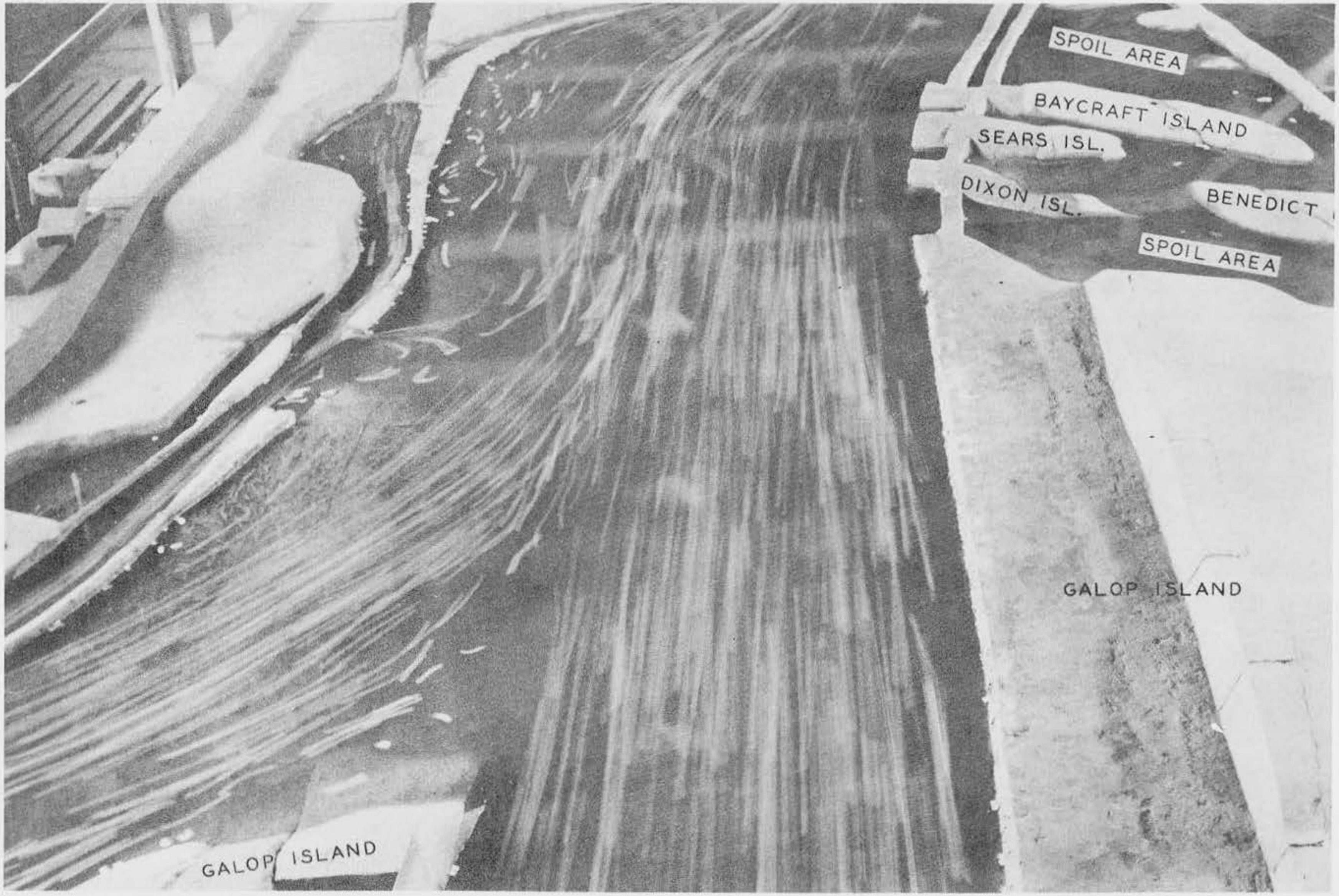
PHOTOGRAPH 36

Final Alternate Plan -- downstream view of navigation channel, vicinity of Butternut Island

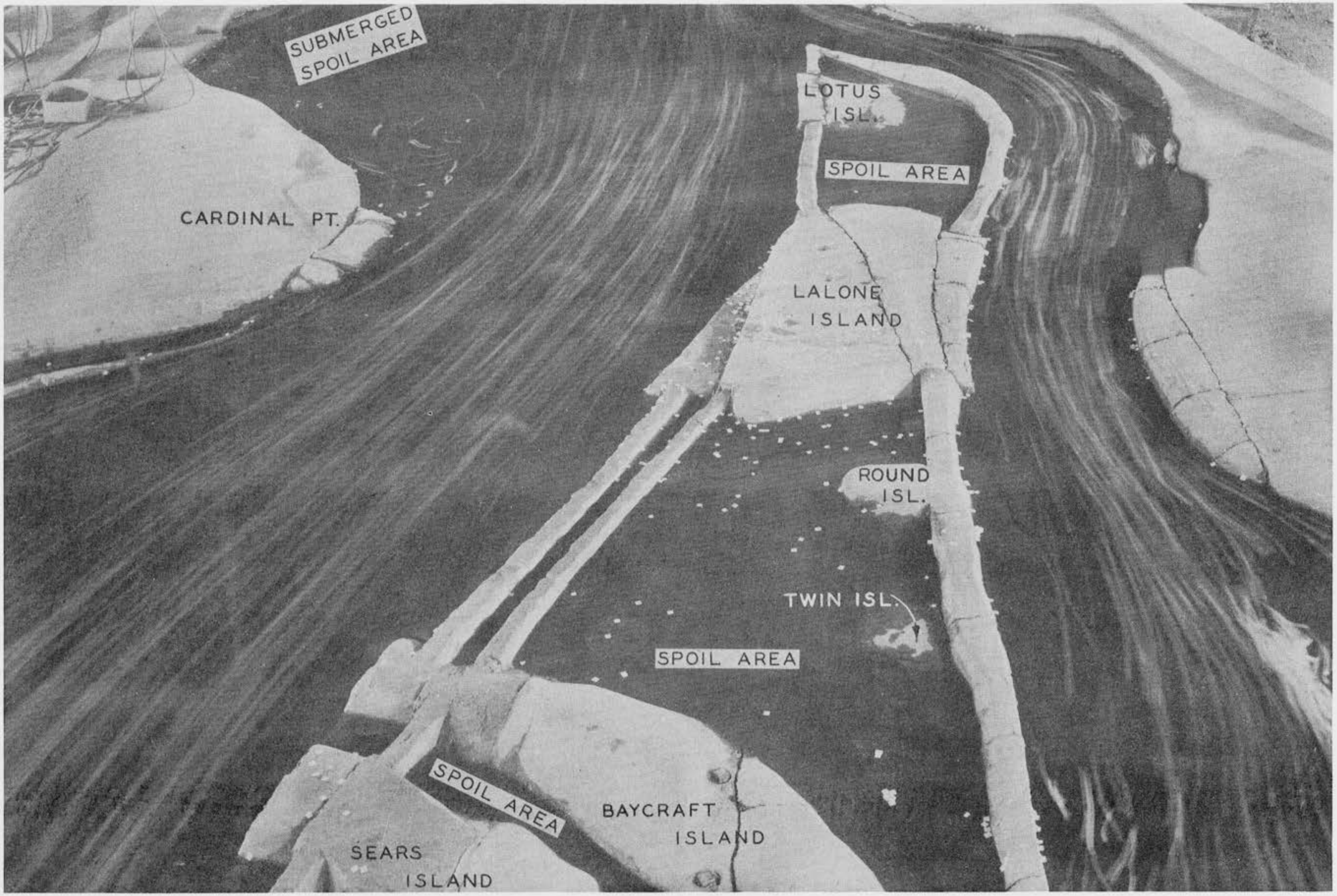
PHOTOGRAPH 37

Final Alternate Plan -- downstream view of navigation channel, head of Galop Island

PHOTOGRAPH 38

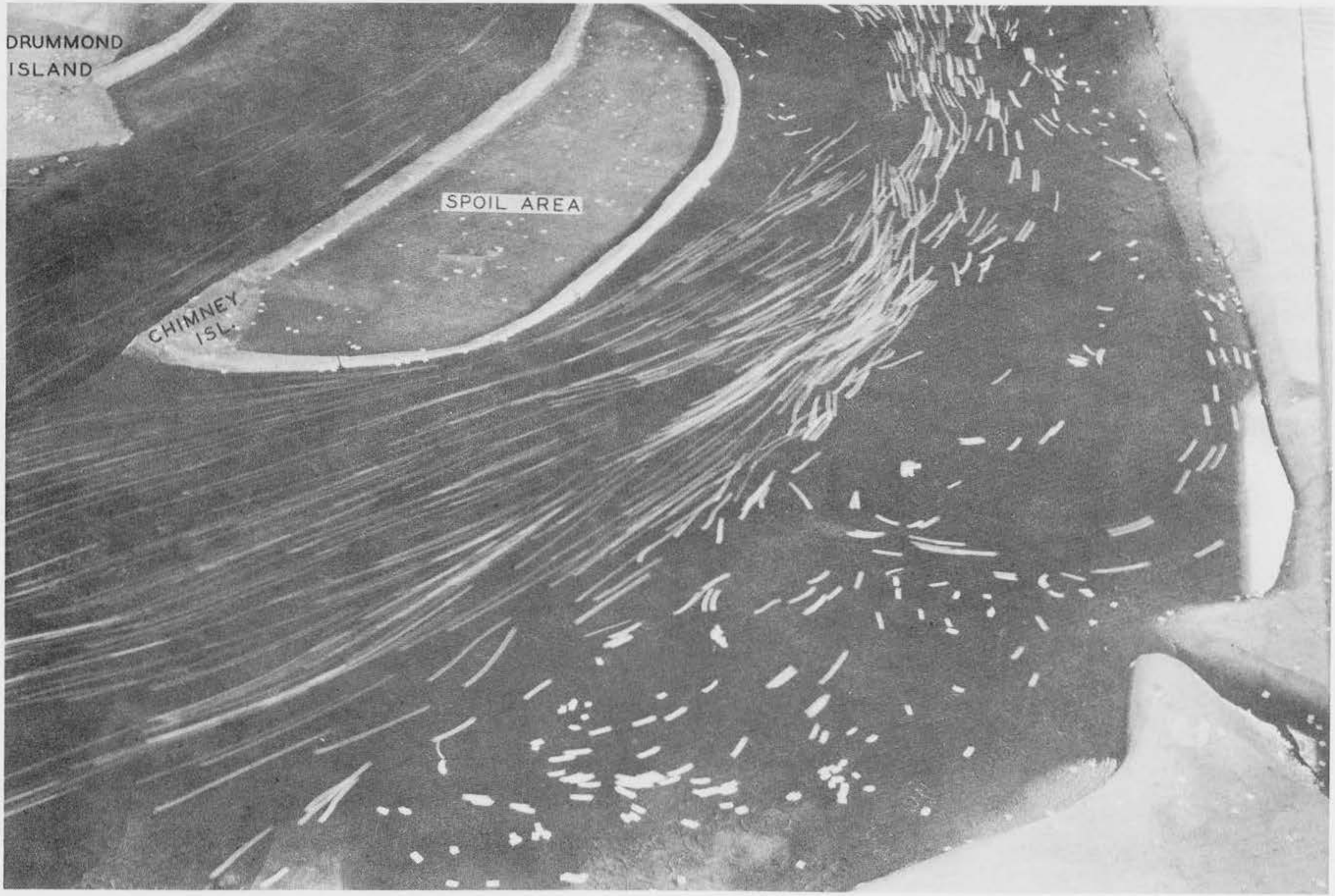


Final Alternate Plan — downstream view of navigation channel below Galop Island

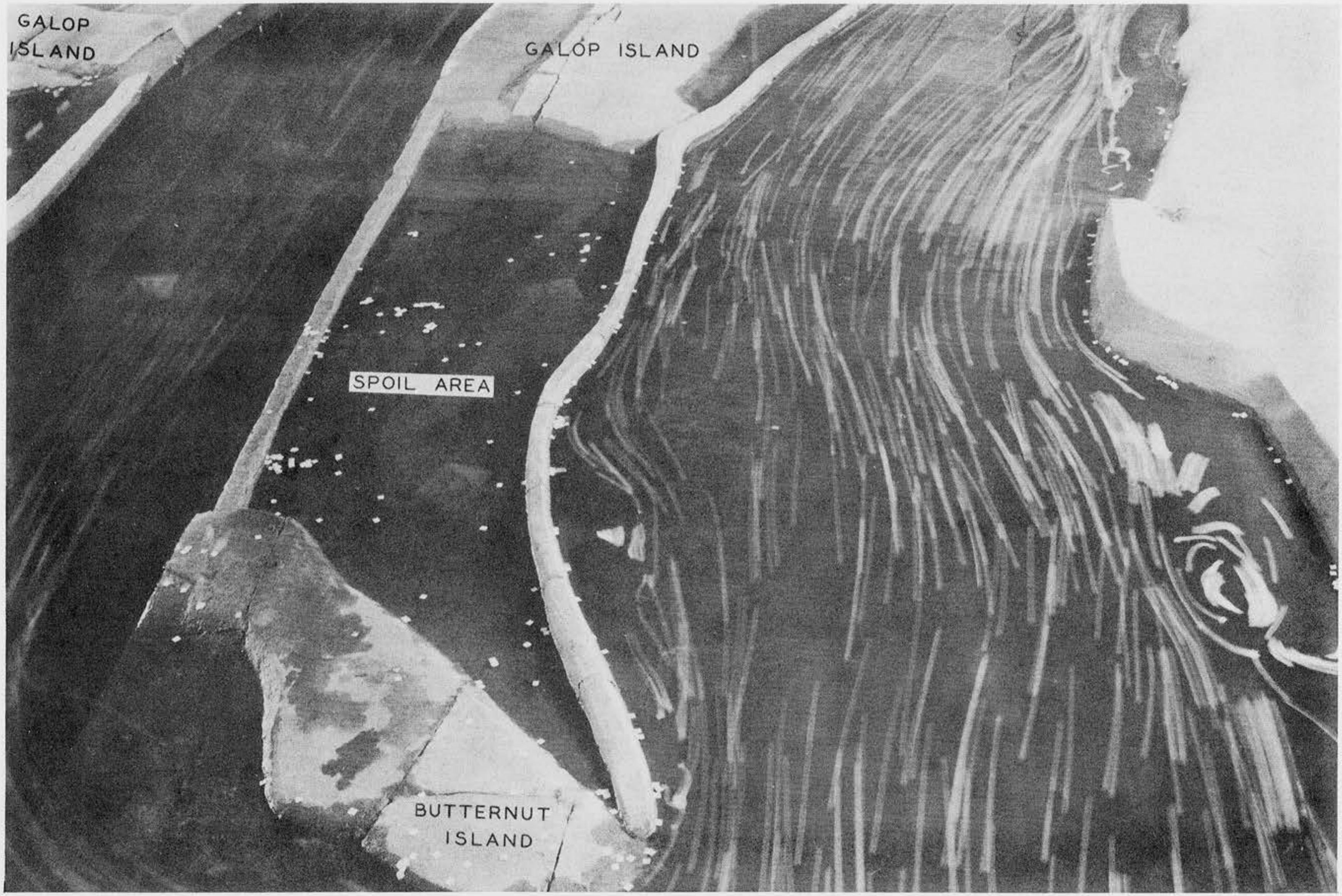


PHOTOGRAPH 39

Final Alternate Plan -- downstream view of navigation channel at Cardinal Point and hydraulic relief channel through Lalone and Lotus Island south channel



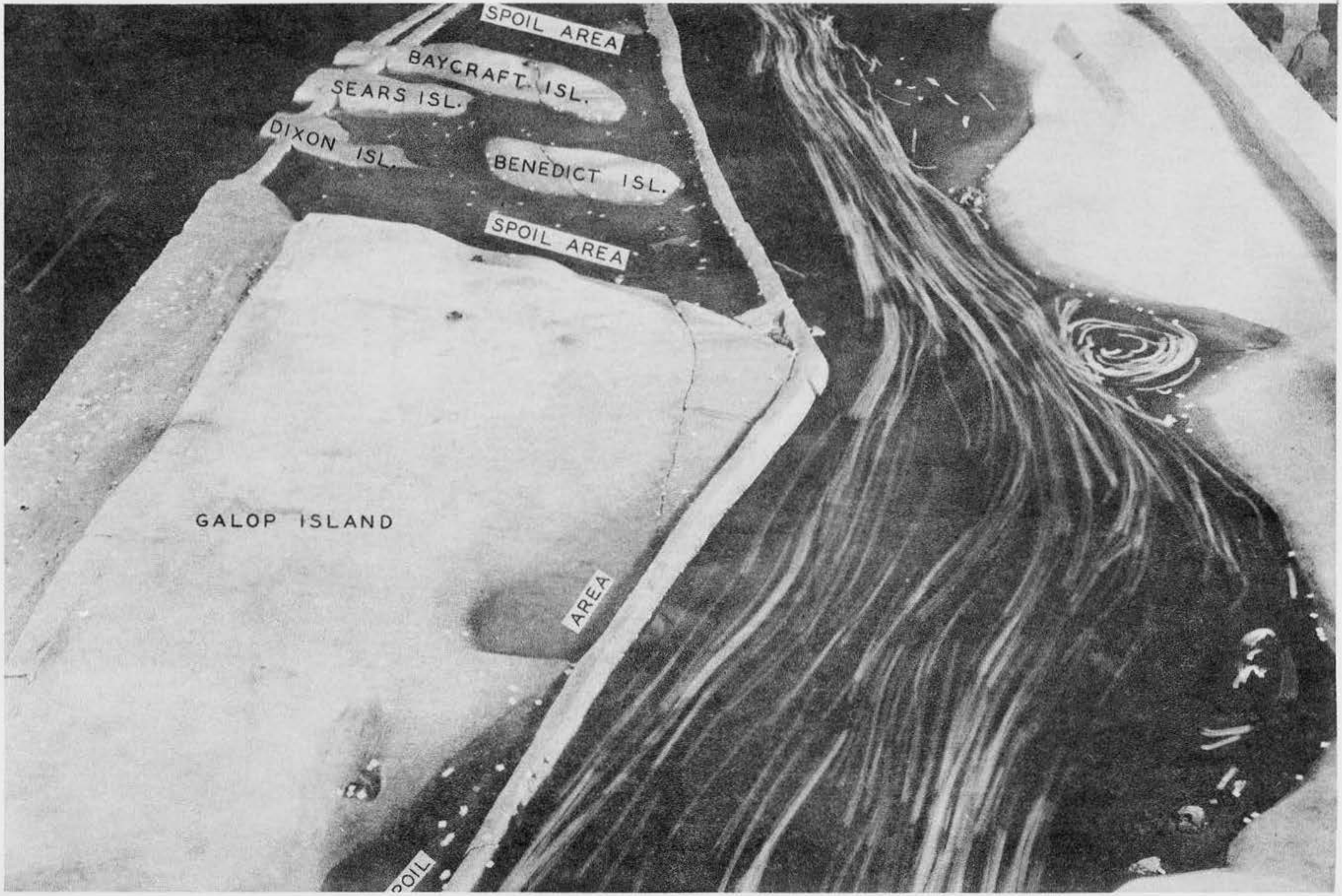
Final Alternate Plan -- downstream view of Chimney Point Channel



Final Alternate Plan -- downstream view of Galop Island south channel, head of Galop Island

PHOTOGRAPH 41

PHOTOGRAPH 42



Final Alternate Plan -- downstream view of Galop Island south channel

Final Alternate Plan -- downstream view of Galop Island north channel

PHOTOGRAPH 43